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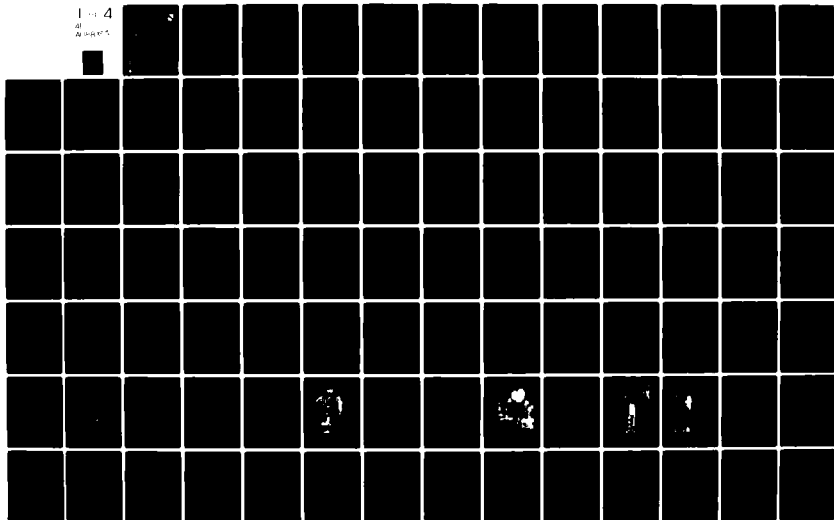
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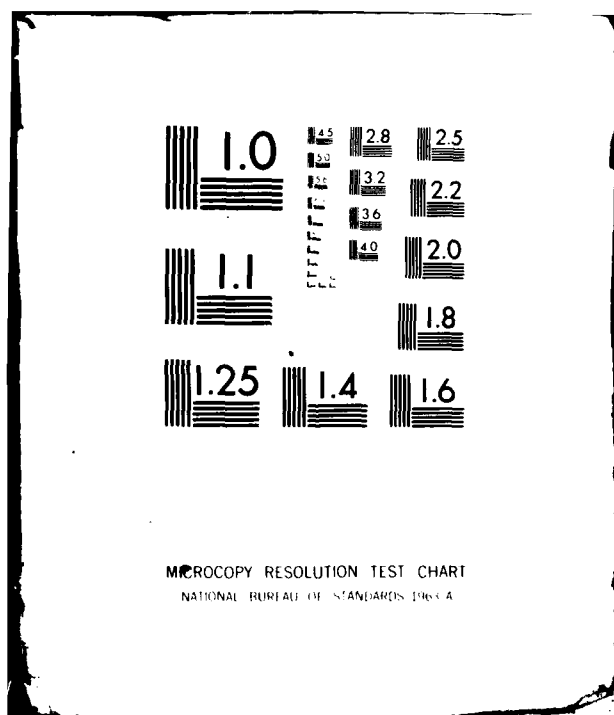
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**FEASIBILITY AND  
CONCEPTUAL DESIGN STUDY  
TO ADD A DEADLOAD TEST  
CAPABILITY TO THE AIRCRAFT  
ARRESTING SYSTEM COMPLEX  
AT EDWARDS AIR FORCE BASE**

Prepared under AF Contract  
F04611-70-C-0030  
by All American Engineering Company

**GEORGE C. MCINTOSH  
MILTON O WOOD**

**TECHNICAL REPORT No. 70-21**

**MAY 1971**

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**AIR FORCE FLIGHT TEST CENTER  
EDWARDS AIR FORCE BASE, CALIFORNIA  
AIR FORCE SYSTEMS COMMAND  
UNITED STATES AIR FORCE**

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GEORGE C. MCINTOSH  
MILTON O. WOOD

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## FOREWORD

This report was prepared by All American Engineering Company, Wilmington, Delaware, under Air Force Contract F04611-70-C-0030 and submitted in September 1970. This contract was initiated under BPSN P68C078, Project Number 1013000XKA0001 and Program Element Number 63101F. The work was administered under the direction of the Air Force Flight Test Center, Edwards Air Force Base, California. The project officer was Mr. Gerald K. Lawson (XOXL/FTTED).

The report summarizes the results of a study conducted during the period from February 1970 through September 1970.

A draft of this report titled "Feasibility and Conceptual Design Study to Add a Deadload Test Capability to the Aircraft Arresting System Complex at Edwards Air Force Base" was submitted for approval in July 1970.

All American Engineering Company wishes to acknowledge the assistance of several organizations, both military and civilian, which contributed to this study. Personnel of these groups aided in the evaluation of present systems, mission requirements and future concepts.

1. Naval Air Test Facility  
Naval Air Station  
Lakehurst, New Jersey
2. Naval Air Engineering Center  
Philadelphia, Pennsylvania
3. Deputy for Engineering  
Equipment Development Branch  
Aeronautical Systems Division  
Wright-Patterson AFB, Ohio
4. Deputy for Systems Test  
Flight Test Engineering Division  
Air Force Flight Test Center  
Edwards AFB, California
5. Plans and Requirements Office  
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10. Hercules Incorporated  
Chemical Propulsion Division  
Magna, Utah
11. Bethlehem Steel Corporation  
Philadelphia, Pennsylvania

A special note of appreciation is directed towards Industrial Education Institute, Boston, Massachusetts, who granted permission to use and reproduce their systematic decision analysis concept known as "Emphasis Curve" written by Mr. Don Fuller.

Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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## ABSTRACT

A feasibility and design study was conducted to provide design requirements and cost estimates for a proposed expansion of the existing Air Force capability for testing aircraft arresting systems and hooks at the Air Force Flight Test Center (AFFTC) Arresting Systems Test Complex. There is no facility within the Department of Defense or industry other than the AFFTC which is capable of being expanded at minimal cost to satisfy the high speed, heavy weight test requirements which must be met during the next decade. A requirement now exists for the development and subsequent testing of one or more high energy arresting gear systems capable of arresting aircraft at engaging speeds of 235 knots. The primary purpose of this study is to define facility requirements and a safe method of testing and evaluating high energy arresting gear systems between the presently obtainable 170 knots and the required 235 knots. This study proposes the use of unmanned test vehicles, called deadloads, to be used above the speed range considered safe for live, manned aircraft test operations, and a facility with a total energy capability 10 to 12 times the capability of any existing facility in this country. It then considers the optimum method of propulsion and guidance for one or more deadload vehicles, with cost studies of the prime and alternate systems, considers alternate uses for the facility which would be useful to the Air Force and other government agencies and provides a conceptual design of the complete proposed overall expansion in stages which covers the full range of weight and velocity requirements projected through the next decade. All known practical propulsion and guidance systems were examined and compared using pertinent weighed parameters to determine the optimum system. The propulsion concept chosen is a variable weight modular deadload pushed by a multi-turbojet engine car (jet car) which is coupled to the deadload. Two jet cars having different power characteristics are proposed for short and long range test requirements. Engines selected are the J79-5 and prototype TF-39's based on present and future availability. With these engines the full speed and weight range capability can be realized within the acceleration run as it now exists as far as all current and proposed Air Force aircraft are concerned. Meeting the complete spectrum of aircraft which includes proposed commercial passenger and cargo aircraft will require the addition of a 2000 foot long  $\times$  50 foot wide extension to the existing runway. The guidance system chosen is two flush parallel tracks which allow deadload and live aircraft testing without extensive set-up time between the two modes of operation. Each of these tracks is composed of dual special shape beams with a slot between them to allow inverted "T" shaped guides to slide down the track and restrain the jet car and deadload vehicles. The facility additions chosen are of a portable type to facilitate relocation of these elements in the event the track is elongated at some future date. The test equipment and facility additions were designed on a conceptual basis so that the next step in the procurement cycle is detail design and procurement.

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## SECTION I

### INTRODUCTION

An adequate facility for testing high speed/heavy weight aircraft does not currently exist within the Air Force, any other Department of Defense Agency or contractor. Present and future test directives being issued to the Air Force Flight Test Center at Edwards AFB require this capability.

A study has been authorized and conducted for the purpose of supplying the conceptual design requirements for a proposed expansion of the present facility to simulate the energy of motion of aircraft such as the F-4, FB-111, Proposed Supersonic Interceptor, and other Air Force aircraft planned for procurement, as well as the heavy commercial transports.

The arresting gear test facility at the AFFTC is the only one that exists within the Air Force; it has a unique, nature provided, adjacent dry lake bed which makes it ideal for the operation of manned aircraft test vehicles. All presently available test vehicles are non-airworthy Class 26 aircraft and due to safety considerations these aircraft are limited to ground roll end speeds five knots below the takeoff speed for the configuration being used (approximately 170 knots).

A requirement now exists for the development and subsequent testing of one or more high energy arresting gear systems capable of arresting aircraft at engaging speeds of 235 knots. The primary purpose of this study is to define facility requirements and a safe method of testing and evaluating high energy arresting gear systems between the presently obtainable 170 knots and the presently required 235 knots.

This study proposes the use of unmanned test vehicles, called deadloads, to be used above the speed range considered safe for live, manned aircraft test operations and a facility with a total energy capability 10 to 12 times the capability of any existing facility in this country. It then considers the optimum method of propulsion and guidance for one or more deadload vehicles, with cost studies of the prime and alternate systems, considers alternate uses for the facility which would be useful to the Air Force and other government agencies and provides a conceptual design of the complete proposed overall expansion in stages which covers the full range of weight and velocity requirements projected through the next decade.

## SECTION II

### EXISTING FACILITIES SURVEY

The following facilities which are or have been directly associated with the testing of aircraft arresting systems and associated systems were visited to view the facility and to discuss capability, operational considerations, future testing requirements and equipment limitations:

Air Force Flight Test Center, Edwards, California  
Naval Air Test Facility, Lakehurst, New Jersey  
Naval Air Engineering Center, Philadelphia, Pennsylvania  
All American Engineering Company, Georgetown, Delaware

#### 1. EDWARDS ARRESTING GEAR TEST FACILITY

##### a. Description of Facilities and Equipment

The existing arresting gear test facility at Edwards AFB is located on Runway 06-24. This runway is six inch thick concrete, 300 feet wide by 8000 feet long with a 2000 foot long macadam overrun area on the Northeastern end with a transition onto the Rogers Dry Lake. At station 6000 or 2000 feet from the overrun end, the arresting gear test area is located. This area contains a control building, an instrumentation building, two pits located below ground level on either side of the runway with a below runway interconnecting tunnel and a runway slot (with access from tunnel) for cable pop-up devices and retractable cable supports. A large area at ground level and the below ground pits are provided to house and anchor the arresting gear under test. The anchoring area consists of beams which are buried in reinforced concrete below ground level such that the top of the beams and concrete are flush with the top surface of the runway or the pit floor. Aircraft currently in use on the test runway are one each F-100, A-3A, F-4 and F-111. Other aircraft available but not in current use are one each B-47 and B-52. Extensive modifications have been made to the test aircraft for test requirements and added safety for high-speed ground testing.

##### b. Method of Operation

Past and present testing of Air Force arresting systems are conducted by utilizing manned, hook and non-hook equipped aircraft. In operation the gear under test is made ready and the aircraft is taxied down the runway and into the gear at varying weights and speeds to establish or check the performance of a new arresting system or compatibility of new aircraft with an existing arresting system. Instrumented data is gathered on both the arresting system and on the tailhook or landing gear struts on the aircraft. After a given test event, the arresting system is retracted, checked, and the aircraft taxied back to the

06 end of the runway in preparation for the next event. Upwards to six test events are normally made consecutively before the site operations are halted and the data checked in the normal operating mode. The operations are limited by safety considerations on the high speed end of the test requirements since the aircraft tend to become light on their main wheels and become partially airborne. This situation increases the possibility of having the hook fail to pick up the wire rope runway pendant. Personnel hazards are greatly increased should an arresting gear or aircraft failure occur while the aircraft is at flying speed. Therefore, personnel safety places severe limitations on any requirement to taxi at or above flying speed (and flyable aircraft must be used). As a result some data points at the high energy range of the spectrum must be extrapolated.

c. Manning Requirements

Total number of personnel required to conduct typical test engagement, such as for the Dual BAK-12/FB-111 Category II test, is 24. These people are required at the test site during active testing. This number can be subdivided by jobs as follows:

5	Firemen
1	Crash Recovery
1	Ambulance/Medic
1	Pilot
3	Aircraft Maintenance Crew
1	Aircraft Instrumentation
3	Arresting System Maintenance
2	Instrumentation
2	Photographers
1	Instrumentation Engineer
1	Site Foreman
2	Test Engineers
1	Test Engineer

This number of people would be reduced to 21-22 for a test where the aircraft and the arresting system are less complex such as the F-4 or F-100 and a single BAK-12 or the BAK-13 arresting systems.

d. Capability of Facility

As the test site is currently configured it is capable of supporting category II aircraft tests into the single or dual BAK-12 or BAK-13 arresting systems, within the operational limits noted previously. Testing is accomplished with live aircraft only with the upper engaging velocity limit set at 160 knots. Large gross weight aircraft, i.e., in excess of 350,000 pounds when taxied onto and over the test runway have caused failure of the six inch thick concrete pads which comprise the runway.

e. Cost of Installation and Operation

Exclusive of the cost of the original runway it is estimated that the installation cost of the present arresting gear test facility was one million dollars including installed instrumentation and equipment.

The majority of arresting gear test manning is provided by central organizations which support all types of AFFTC test projects. Personnel which can be identified specifically as full time assignment to arresting gear testing are:

- 1 Site Foreman
- 2 Mechanics, Arresting System
- 3 Instrumentation
- 3 Test Engineers
- 3 Aircraft Maintenance Crew

During non-test time other support is provided by aircraft maintenance specialists, civil engineering, instrumentation calibration labs and instrumentation engineering. Computer support and programming is provided by a central data facility. Cost of operation for a typical program such as the BAK-13 is \$1,500 to \$2,500 per test engagement where rate of testing is 30 to 40 tests per month. This includes all direct labor noted above plus materials, computer and plotter time, and film processing. It includes aircraft fuel and maintenance but does not include aircraft spares. Also no allowance was made for cost of initial installation of test arresting equipment.

2. NAVAL AIR TEST FACILITY

a. Description of Facilities and Equipment

The Naval Air Station, Lakehurst, was expanded beginning in 1957 with the addition of the Naval Air Test Facility. This facility was designed originally to test and evaluate shipboard, i.e. aircraft carrier, launching and recovery equipment. As the equipment came into being, the NATF was and is used for the evaluation of various land based catapult and arresting gear systems which were scheduled for use by the Marine Corps as part of the Short Airfield for Tactical Support (SATS) concept for limited warfare.

The facility consists of one 12,000 foot long runway and five jet car tracks with provisions for testing up to five arresting gear systems simultaneously. On one end of the 12,000 foot runway there are two steam catapults which are in operational use and at station 6000 there are underground provisions for housing the Mark VII arresting gear which is used operationally aboard aircraft carriers. One steam catapult is installed in an elevated position to more closely simulate the bow of a carrier whereas the second is installed flush with the surface of the runway. A steam generating plant is located in an area adjacent to



the steam catapults. Three aluminum matting runways intersect the long runway at an angle of three degrees and have been used to test a series of land based SATS catapults.

The jet car tracks are physically arrayed in a fan-like pattern when viewed from the air. The following is quoted from reference (1) which is included in this report as part of Appendix I.

"(1) A Recovery System Track Site (RSTS) consists of a double-rail jet car track that is used for testing the various arresting gears or components, plus barriers, barricades or components, and aircraft components.

(2) A four-wheeled jet car, powered with J-48 engines, is used as a launching device and source of energy. Present jet cars are arrested by a system of trailing friction brakes which, at the end of the launching run, engage a thickened section of track rail. Braking force is adjustable up to a maximum of 13,000 pounds per brake unit.

(3) The characteristics of a typical track site at NATF are as follows:

Reinforced Concrete	
Length (in feet)	7,800
Track width (in feet)	28
Free-run width (in feet)	40
Slab thickness (in inches)	12
Design strength of wheel load (in lbs.)	54,000
Guide rails	
Length (in feet)	7,408
Cross section (inches WF 49)	10
Spacing, centerline (in inches)	52-1/2
Brake rail (movable) (length in feet)	900
Runout Area	
Paved length (in feet)	1,400
Paved width (in feet)	200
Cleared over-run area (length in feet beyond the paved area)	1,000

(4) The model 656 (modified) jet car characteristics are as follows:

Engine (four)	J-48-P-8
Number of Wheels	4
Tire size (inches)	30 x 7.7
Thrust (pounds)	24,000

Fueled weight (pounds)	18,000
Length	21 ft. 4 in.
Width	17 ft. 7 in.
Maximum speed (knots)	260
Maximum design deceleration (G)	8

(5) At the launch end of the track site, there is a control building from which the jet engines are started and brought to required RPM to obtain the desired thrust for the particular test event. Two buildings are located at the arresting end of the track site. One building houses the data recording equipment while the other serves as a work area for the maintenance of the arresting gear.

(6) In addition, two backup arresting gears are installed in the run-out area. One gear is for the purpose of arresting a runaway deadload should the primary gear fail, while the other is used as an anti-coastback device to protect the facilities if the deadload were to walkback excessively.

#### b. Method of Operation

(1) An engineer from the Recovery Division is in charge of the test program. A Site Officer (Naval) is charged with the duties of coordinating the launch and recovery ends of the track sites and acting as Safety Officer. The Site Officer is in contact with the launch end by sound-powered phones. When assured that the recovery end is ready, he prepares the site for test and relays the RPM requirements to the launch end to obtain the desired end speed as per the test directive. He gives the word to release the jet car and also announces when the test is complete.

#### c. Manning Figures

The following personnel have to be available to operate and maintain a track site (the personnel marked with an asterisk, however, are required only on a part-time basis):

(1) Five Aircraft Launching and Arresting Devices Mechanics to operate and maintain the arresting gear under test, the back-up arresting gears, and serve as road and fire watchers during tests.

\*(2) Two Aircraft Launching and Arresting Devices Mechanics to maintain and repair deadload and arresting gear components.

(3) Three Aircraft Engine Mechanics to operate and maintain jet engines and jet cars.

\*(4) Two Aircraft Engine Mechanics to maintain brakes, overhaul jet engines, and repair jet car components.

(5) One Supervisor.

\*(6) One Tractor Operator to push deadloads and jet cars back to launching end of track site.

\*(7) Four Electronic Technicians at Recovery end of track site to operate data recording equipment.

\*(8) Six Electronic Technicians for support services in maintaining and installing data recording equipment.

\*(9) Two photographers to record test events.

\*(10) Two laboratory personnel to process filmed data.

(11) One Test Engineer.

\*(12) One Materiel Personnel to obtain and issue components for repairs, installation, and maintenance.

d. Capability of Facility

(1) It is presently possible with the J-48 jet car to launch a deadload to obtain a kinetic energy capacity of 79 million foot-pounds. For tests requiring higher energy levels than those presently obtainable with the J-48 jet car, additional launching energy is obtained by installing JATO units on the test vehicle. By increasing the number and size of the JATO units, it is possible to significantly increase the energy levels.

(2) In view of the higher energy requirements necessary for further test operations, NATF is presently modifying an existing jet car to utilize J-79 engines as a source of power. This modified jet car will have approximately 58 percent more energy than the present jet car.

(3) For the express purpose of performing the above functions, deadload test vehicles are available to obtain any desired weight ranging from 8,000 to 110,000 pounds. Also available are deadload aircraft (stricken) used to simulate the actual entry of aircraft into an arresting system. Available are the A-4, F-4, A-3, F-111, and F-8 deadload aircraft. (The F-111 does not have a nose gear; however, a nose gear can be "jury-rigged" if a need existed).

e. Cost of Installation and Operation

The costs listed are approximations of present day costs:

Recovery System Track Site	\$1,655,000
Jet Engine Remote Starting Building	6,000
Data Acquisition Building	25,000

Recovery Maintenance Building	22,000
Jet Car (engines and starting system assumed to be GFE)	250,000
Deadload (Type I) (8,000 - 16,000 pounds)	25,000
Deadload (Type II) (15,000 - 35,000 pounds)	70,000
Deadload (Type III) (30,000 - 110,000 pounds)	125,000
Instrumentation for Data Acquisition Site	250,000
Deadload Telemetry Packages	10,000
Photographic Equipment and Electrical Facilities	19,000
Tractor (to push deadload and jet car back to launch end)	15,000
Maintenance Shop (for jet engine repair, brake overhaul)	50,000
Labor and Material costs for one day's operation (based upon sustained daily operations at NATF)	2,200

f. Description of Current "State of the Art" Equipment with its Capabilities, Deficiencies and Limitations.

Since the track and jet car capabilities have been discussed under paragraph (d) they will not be repeated here. The instrumentation capabilities are as follows:

(1) The record and quick-look capability system available at the RSTS area is a Direct Record FM/FM Multiplex System with the following items at a site:

(a) Ampex FR-100A (with ES-100 Electronics) tape system, one-inch tape with fourteen tracks.

(b) Time-of-day code and a six-digit identification number in BCD form, 100 pulses per second recorded as 10 KC and 13 KC Tone Bursts (Hermes Tone Burst Format).

(c) Telemetry Receivers (two each)

(d) Voltage Controlled Oscillator - 64 each (land line data channel limit) IRIG proportional BW.

(e) Low-level Differential Amplifier - 40 each.

(f) Transducer Condition capability.  
48 Low-level (strain gage) channels.  
24 High-level channels

(g) Honeywell Visicorder Model 1612.

(h) Demultiplexers - 31 each.

(i) Dual-corner reflector antenna.

(2) Deadload telemetry packages available have up to sixteen continuous data channel capability.

(3) Photographic instrumentation includes Pin registered cameras with speed ranges of 100 - 500 frames per second, high-speed cameras with speed ranges from 100 - 1000 frames per second, ultra-high speed cameras, miscellaneous equipment including lenses, tripods, editing equipment, still and sequence cameras, battery packs and camera control systems. The laboratory equipment will not be delineated here since it is the normal equipment necessary to process the data obtained with the equipment as noted.

(4) Coupled with the arresting gear and instrumentation equipment, support facilities are maintained and updated in order to maintain pace with the "state of the art". It is not enough to collect data; it must be analyzed and disseminated. The digital computational facility provides for scientific problem solution, management information systems, and scientific data reduction of mass data acquired at the track site. Equipment includes a CDC 160 Digital Computer, four CDC 164 tape drives, one on-line CDC 165-2 card reader, one on-line Anelex series -5 160 character printer, one on-line CDC 165-2 digital incremental recorder, one CALCOMP 565 digital incremental recorder. Inputs are prepared on two off-line Friden Model F flexowriters, one IBM model 026 keypunch and test data is digitized on one off-line CSC Microsadic Model II A/D converter. Machine language plotting routines are included.

(5) In conjunction with the digital computational facility, an analog computational facility is available. Its primary function is to process and convert analog data recorded on magnetic tape to a digital format suitable for digital computer reduction. Equipment includes an Arnoux Pulse Amplitude Modulation Decomcommunicator, an EAI 16-31R analog computer for data manipulation of data filtering and branching networks provide for data termination in two 36-channel oscillographs and a 40-channel analog to digital converter with a gapless binary format tape. The analog computer can be operated for off-line solution of scientific problems with outputs on an X-Y plotter.

(6) In order to collect accurate data, there is available an instrumentation calibration and development facility. Included in this facility is a strain gage installation shop, a transducer calibration laboratory, and an electronic calibration laboratory. This facility manufactures, calibrates and maintains electrical transducers and associated electronic data handling equipment used in support of test and evaluation of arresting devices. The major equipment used by this facility is a deadweight pressure tester, a 100 g centrifuge, a frequency generator, and an electric furnace.

(7) Also available is the tensile calibration test facility which has a universal tensile testing machine which has a capacity of 400,000 pounds. Coupled with the tensile tester is a function generator, a rate programmer and a curve follower to produce any type of function, cycle, and tension or compression input."

g. In addition to the Recovery System Track Sites described above and as noted previously this facility also has the runway site for testing catapult and arresting systems and components. The site allows the hook-up and launching of either deadloads or live aircraft in a manner identical to that used on carrier decks. In the case of the deadloads these trail the same type of friction brakes used on the jet cars and work in the same manner. A launch operation consists of positioning the vehicle to be launched in the starting or battery position and attaching a weak link holdback fitting in between fittings on the aircraft or deadload and the holdback anchoring device on the deck or runway. A wire rope connection is then made between the hook on the catapult shuttle and the launch hook or hooks on the deadload or aircraft. Next the bridle is tensioned; the vehicle is then launched on a signal from the catapult officer. At the end of the launch stroke the shuttle is decelerated in a five foot stroke; the vehicle is disengaged from the shuttle and is free to go along until it is decelerated by the trailing brakes in the case of the deadload or fly in the case of the aircraft. In the latter case, the aircraft may stay up for some time to decrease the fuel load and then make a fly-in landing into the Mark VII arresting gear located at the mid-point of the runway. The alternative is to fly around and make a normal non-arrested landing.

### 3. NAVAL AIR ENGINEERING CENTER

#### a. Description of Facilities and Equipment

NAEC, prior to 1959 was both the Engineering and Test Center for the design and development of launching and recovery equipment. Since that time most of the testing effort has been transferred to the Naval Air Test Facility at Lakehurst.

NAEC was contacted as part of the facilities survey for the prime purpose of discussing design philosophy and some historical aspects of deadloads, jet cars and associated test equipment.

NAEC has designed and has built a prototype Arresting Gear High Cycle Tester which is scheduled for installation at Lakehurst during Fiscal Year 1971. This machine uses a comparatively small power plant and stores the required energy in a flywheel which is released upon demand. The machine is unique since it will have the capability of evaluating an arresting gear system at the rate of one test event every 90 seconds. For a detailed description of this test equipment see Appendix I.

### 4. ALL AMERICAN ENGINEERING COMPANY TEST FACILITY

#### a. Description of Facility & Equipment

The All American Engineering Company Test Facility was established in 1953 at the Sussex County Airport, Georgetown, Delaware. Since that time it has provided testing services to both government and industry.

An overall layout of the facility is shown in Appendix I. There are three test tracks, two of which utilize guided jet cars to propel deadloads of various configurations at velocities to 200 knots. The first track, located in front of the control tower parallel to runway 04-22, utilizes a single surface mounted steel rail for guidance and braking. It is 4500 feet long and is capable of testing both land based and shipboard type energy absorbers. This track was the model for the test tracks at NATF, Lakehurst, N. J. Track Number Two is installed flush with the runway surface and on the centerline of runway 10-28. A number of energy absorbers have been tested on this track including those with energy capacities from  $10 \times 10^6$  foot pounds up to  $200 \times 10^6$  foot pounds. These gears have been used to stop deadloads and live aircraft. The third track was installed for component testing of land based catapults.

Normal propulsion power for the test tracks is supplied by two-engine or four-engine jet power cars; however, propulsion can be supplied by other means as well -- for example, rocket power. JATO and similar type thrust units have been used to augment jet car thrust and can be utilized as an independent power source when the weight and velocity requirements so warrant.

A third source of power has been the Federal Aviation Agency's 50,000 horsepower gas turbine accelerator. Developed by this contractor, it utilizes six turbojet engines. The engines are mounted radially, exhausting inward on a turbine which powers a high speed capstan driven cable. It has been modified to produce kinetic energy in the order of 225 million foot pounds with deadload weights up to 350,000 pounds. The launch cable is installed on the centerline of runway 10-28, adjacent to the jet car track. This permits launching of manned aircraft or deadloads.

In many programs, deadload test operations are followed by testing with live aircraft. The arrangement of test tracks makes it possible to switch from deadload to aircraft tests without costly delays in moving equipment. Flight test operations have been conducted on universal and cross-wind landing gear, in-flight refueling and re-arming, catapults, arresting gear and airborne cargo delivery systems.

There is also a high speed cable test device -- The Packard Test Site, so named because of the engine utilized for power, a 1200 horsepower Packard marine engine. There are two jet or rocket engine test cells. A 70 foot high test tower installed over track one can provide a calibrated air flow through parachutes for a variety of test purposes. A high capacity pull test machine is also available.

b. A test engineer from the Engineering Department is in charge of the overall test program. The tower operator coordinates the launch and recovery ends of the track, or in the case of aircraft operations the ground station and the aircraft. The tower operator is in contact with the launch end and the recovery end by radio. When assured that everything is in readiness, he prepares the site

for test, determines the power requirements of the jet car to obtain the desired speed and relays this to launch end. He gives instructions to release the car and announces completion of the test. In the case of aircraft operations he relays coordinating instructions to the ground station and aircraft.

c. Manning Figures

The following personnel are required to operate and maintain one track site (the personnel marked with asterisk are required on part-time basis only).

- (1) One Test Engineer
- \*(2) One Tower Operator
- \*(3) One Foreman
- (4) Two Jet Car Mechanics
- (5) Three Arresting Gear Mechanics
- \*(6) Two Instrumentation Technicians
- \*(7) One Photographer

d. Cost of Installation and Operation

This facility was developed over a ten year period as requirements necessitated. The costs listed are approximations of present day costs:

Test Track Sites	\$750,000
Jet Car (2 engine)	40,000
Jet Car (4 engine)	100,000
Deadload (15,000 - 36,000 pounds)	35,000
Deadload (350,000 pounds)	125,000
Deadload (Mirage mock-up)	35,000
Deadload (707 mock-up)	70,000
Instrumentation Equipment	200,000
Photography Equipment	10,000
Tractor (to push deadload & jet car to launch end)	4,000
Labor & Material Costs for One Day's Operation (Based on one track sustained operations)	2,000



### SECTION III

#### AIRCRAFT SURVEY

##### 1. PROCEDURE

Data was collected on the pertinent aircraft now in use by the Air Force, those aircraft scheduled for procurement and the larger current and planned commercial jet transports. Data pertinent to this study are the maximum T.O. weight and speed which determines the maximum kinetic energy requirements and the onboard equipment for arrestment, if so equipped. The combination of the energy level and the arrestment method ultimately determines the basic configuration of the arresting system. High velocity engagement of a runway pendant is another consideration that has not been included in this survey.

Table I which follows lists all the subject aircraft, in ascending order of kinetic energy required, their maximum take-off weight and speed, landing weight and speed, the maximum kinetic energy requirement and the type of arresting hook if so equipped.

For record purposes and to graphically depict the wide range of physical characteristics that are encompassed by these aircraft, each is shown to scale in Figures 1 through 15 on those pages immediately following the table. Each figure is displayed to a scale of 1:100.

Figures 16 through 36 are graphic displays of each of the aircraft which show the tire sizes, tire inflation pressure, wheel track, wheel tread and the hook location if the aircraft is so equipped.

TABLE I

## AIRCRAFT DATA SUMMARY

A/C Type	T.O. Weight (lbs.)	Landing Weight (lbs.)	T.O. Speed (kts.)	Landing Speed (kts.)	K.E. at Max. T.O. Config. (ft.-lbs.)	Arresting Hook Emer. Oper. None
T-38	11,700	9,000	160	135	13,288,444	x
F-5B	20,100	12,000	165	135	24,277,964	x
F-5A	19,700	12,200	165	135	23,794,820	x
F-102	32,000	24,000	170	145	41,029,492	x
F-104	22,700	16,000	200	145	48,743,845	x
A-7D	45,000	20,000	165	140	54,353,651	x
F-100	40,000	24,000	180	141	57,498,078	x
F-106	42,700	27,000	180	151	61,379,198	x
F-101	52,700	34,000	185	160	79,565,183	x
F-105	52,500	28,400	203	157	95,984,190	x
F-4	60,000	34,000 to 42,000	190	135-165	96,096,324	x
F-111	125,000	57,000	170	112	160,271,456	x
Proposed Supersonic Interceptor	150,000	75,000	235	140	367,515,203	x
L-1011	409,000	348,000	152	135	419,136,186	x
DC-10-10	410,000	347,000	154	131	431,393,527	x
B-1 Advanced Manned Bomber	350,000	--	200	--	620,916,000	Undecided
C-5A	728,000	--	142	--	650,997,360	x
DC-10-20	515,000	395,000	174	139	691,757,779	x
DC-10-30	555,000	403,000	181	140	806,674,742	x
747	713,000	564,000	169	138	902,061,964	x
747B	778,000	564,000	178	138	1,093,623,736	x
SST	750,000	460,000	197	151	1,291,344,276	x
L-1011 Data from Appendix I						
DC-10-20-30 Data from Appendix I						
747, 747B, & SST Data from Appendix I						



31 FT, 10



31 FT, 2

47 FT, 2

<b>T-38</b>	
MAX. T.O. WEIGHT	17,700 LBS.
LANDING WEIGHT	9,700 LBS.
T.O. SPEED	320 KNOTS
LANDING SPEED	135 KNOTS
K.E. AT MAX. T.O. SPEED	3,249,444 FT. LBS.
<b>F-5A</b>	
MAX. T.O. WEIGHT	20,000 LBS.
LANDING WEIGHT	12,200 LBS.
T.O. SPEED	350 KNOTS
LANDING SPEED	135 KNOTS
K.E. AT MAX. T.O. SPEED	4,277,664 FT. LBS.
<b>F-5B</b>	
MAX. T.O. WEIGHT	9,700 LBS.
LANDING WEIGHT	2,200 LBS.
T.O. SPEED	165 KNOTS
LANDING SPEED	135 KNOTS
K.E. AT MAX. T.O. SPEED	2,794,520 FT. LBS.

ALL AMERICAN ENGINEERING CO.	
PROJECT NO.	T-38 A/C
DATE	100106
BY	100106

Figure 1. T-38, F-5A, and F-5B Aircraft



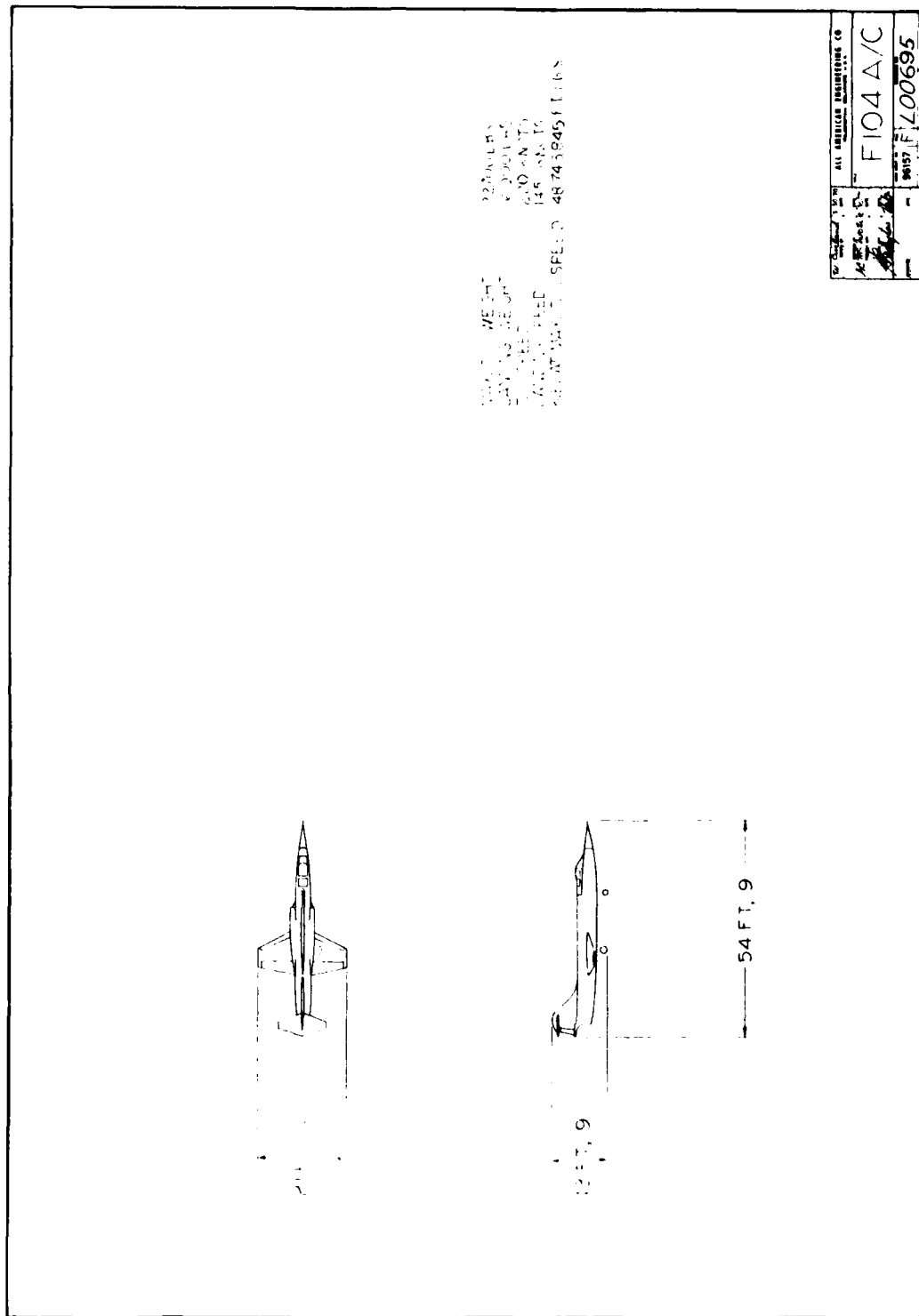


Figure 3. F-104 Aircraft

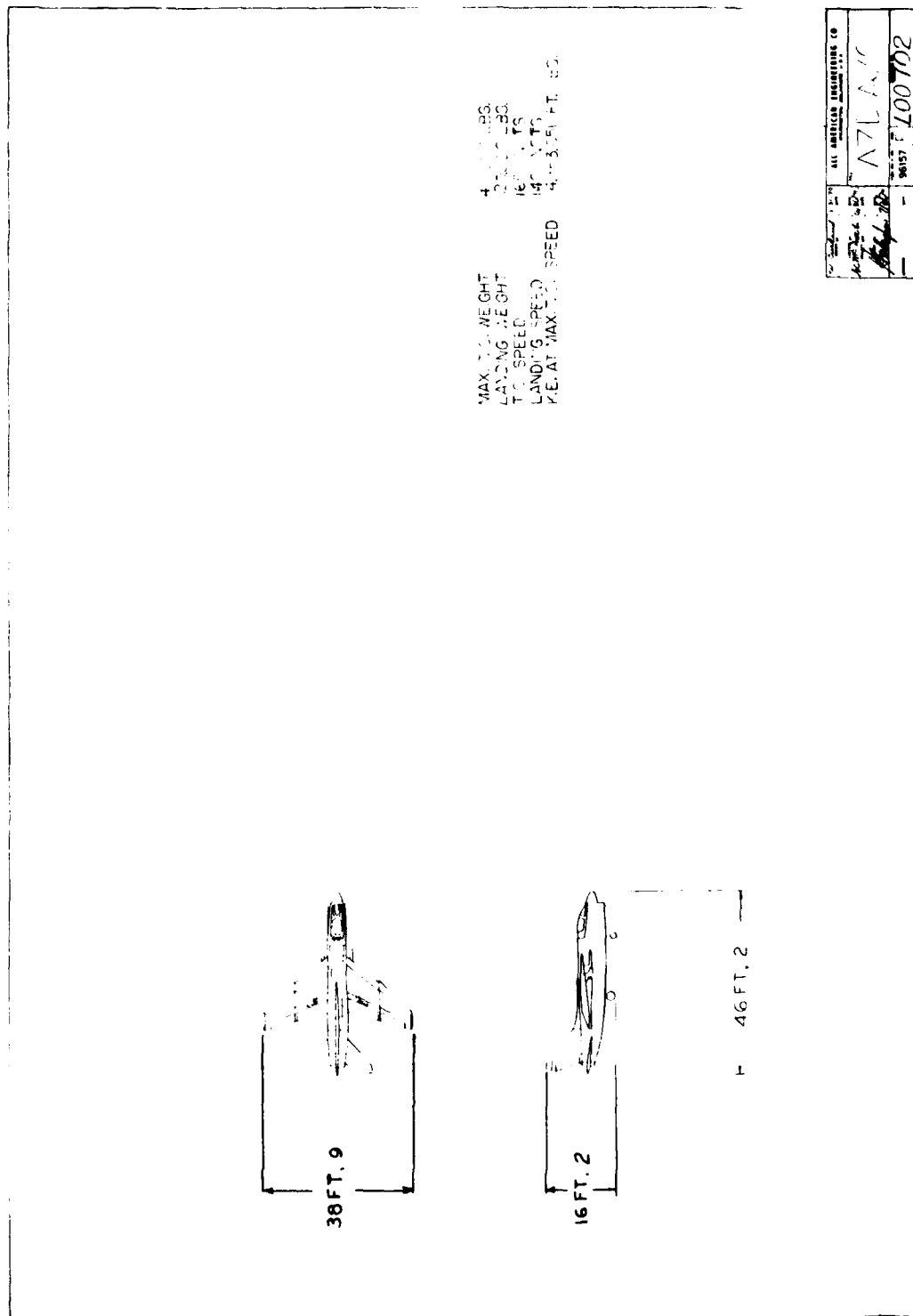
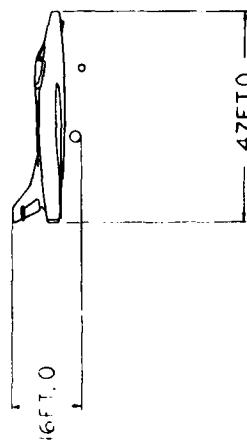
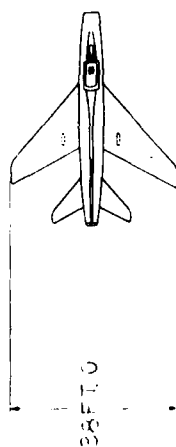


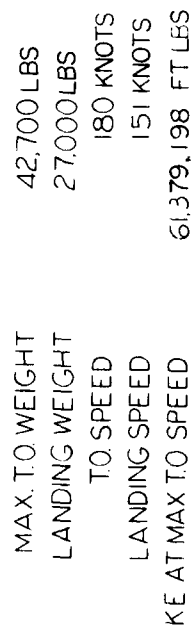
Figure 4. A-7D Aircraft



MAX. T.O. WEIGHT 40,000 LBS.  
 LANDING WEIGHT 24,000 LBS.  
 T.O. SPEED 186 KNOTS  
 LANDING SPEED 141 KNOTS  
 K.E. AT T.O. SPEED 57,496,778 FT. LBS.

ALL AMERICAN ENGINEERING CO.	
F100A/C	
98157	F100692

Figure 5. F-100 Aircraft



ALL AMERICAN CONSTRUCTION CO	F-106A/C	98157 F 100697
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**Figure 6. F-106 Aircraft**



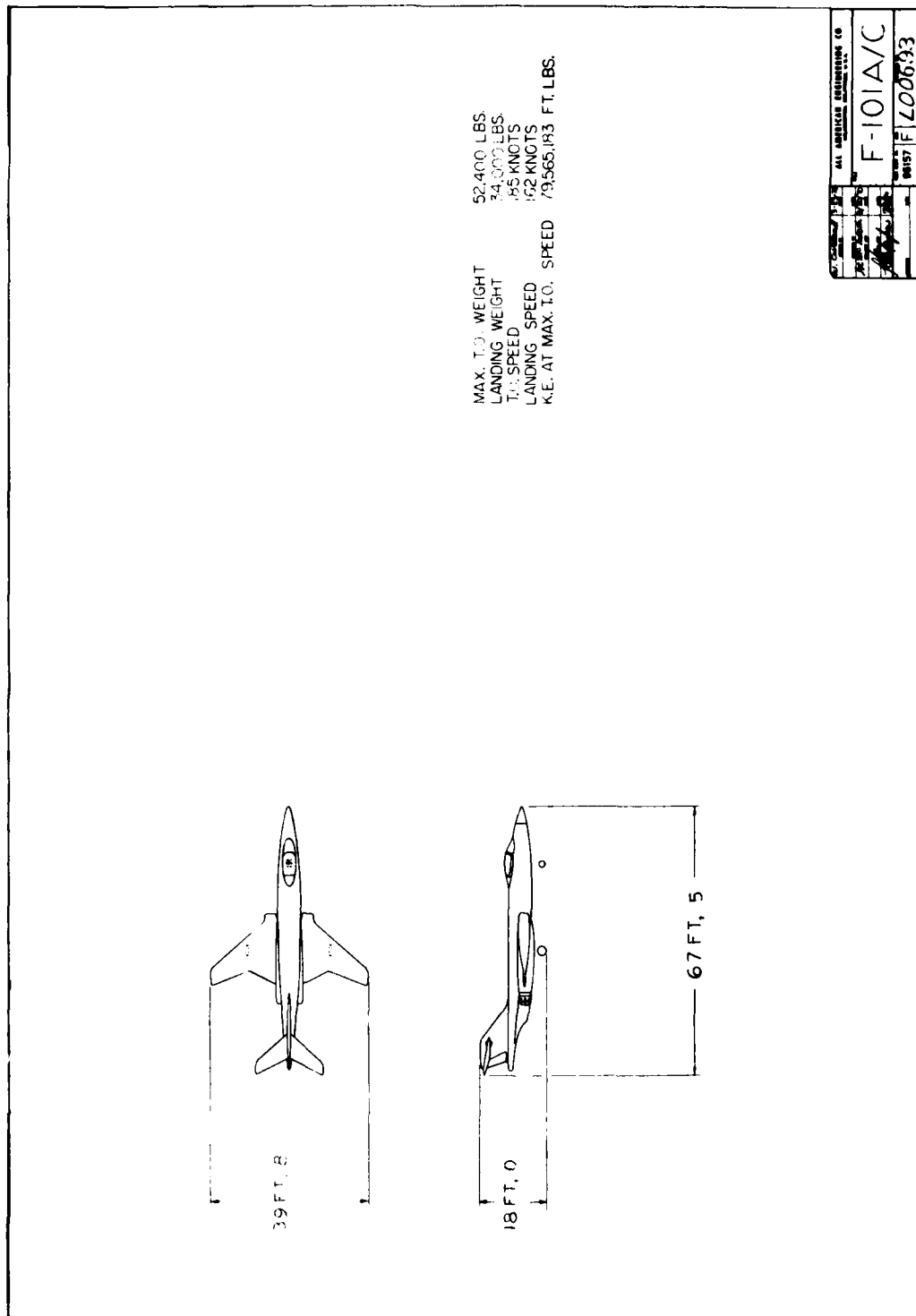


Figure 7. F-101 Aircraft

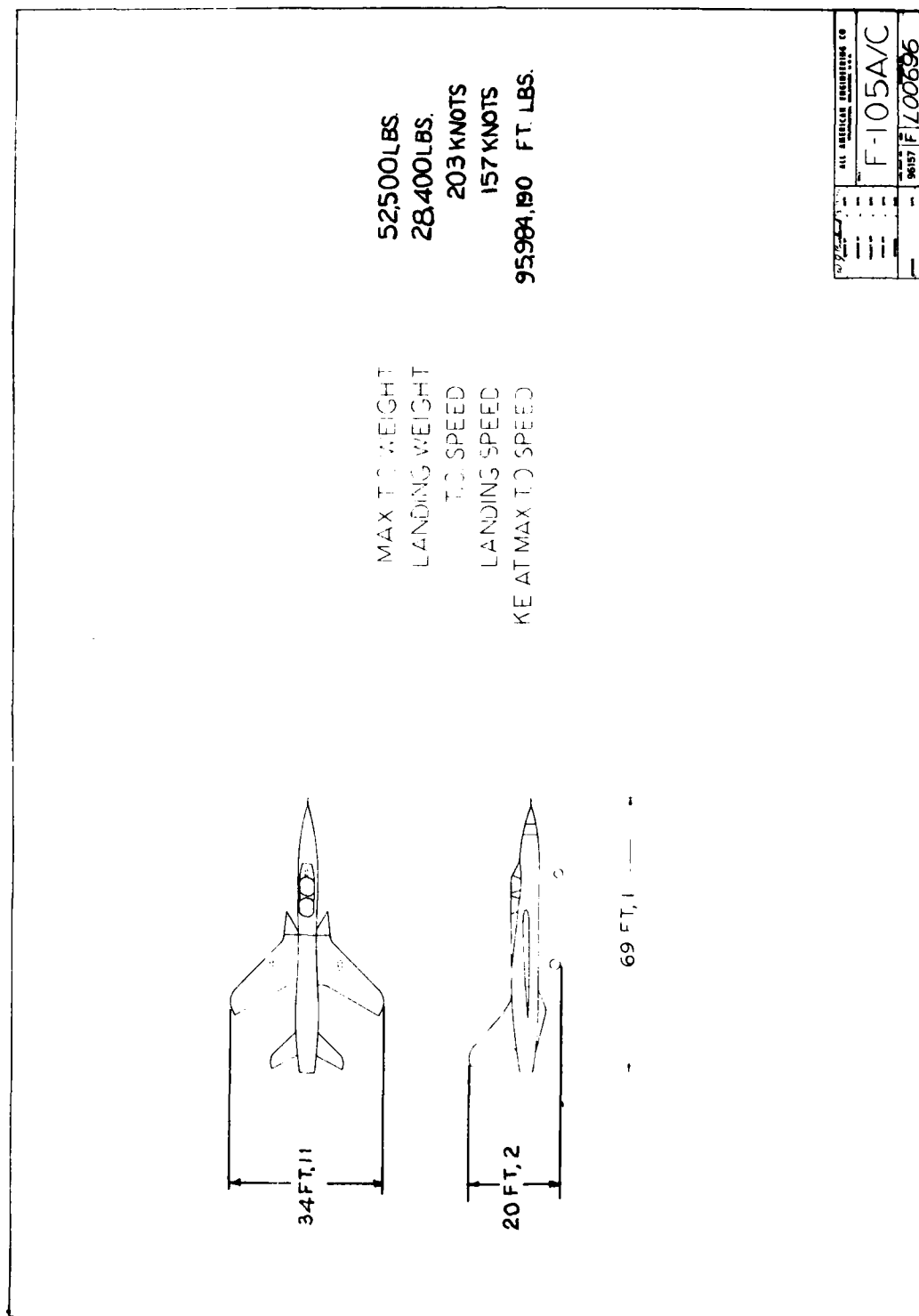


Figure 8. F-105 Aircraft

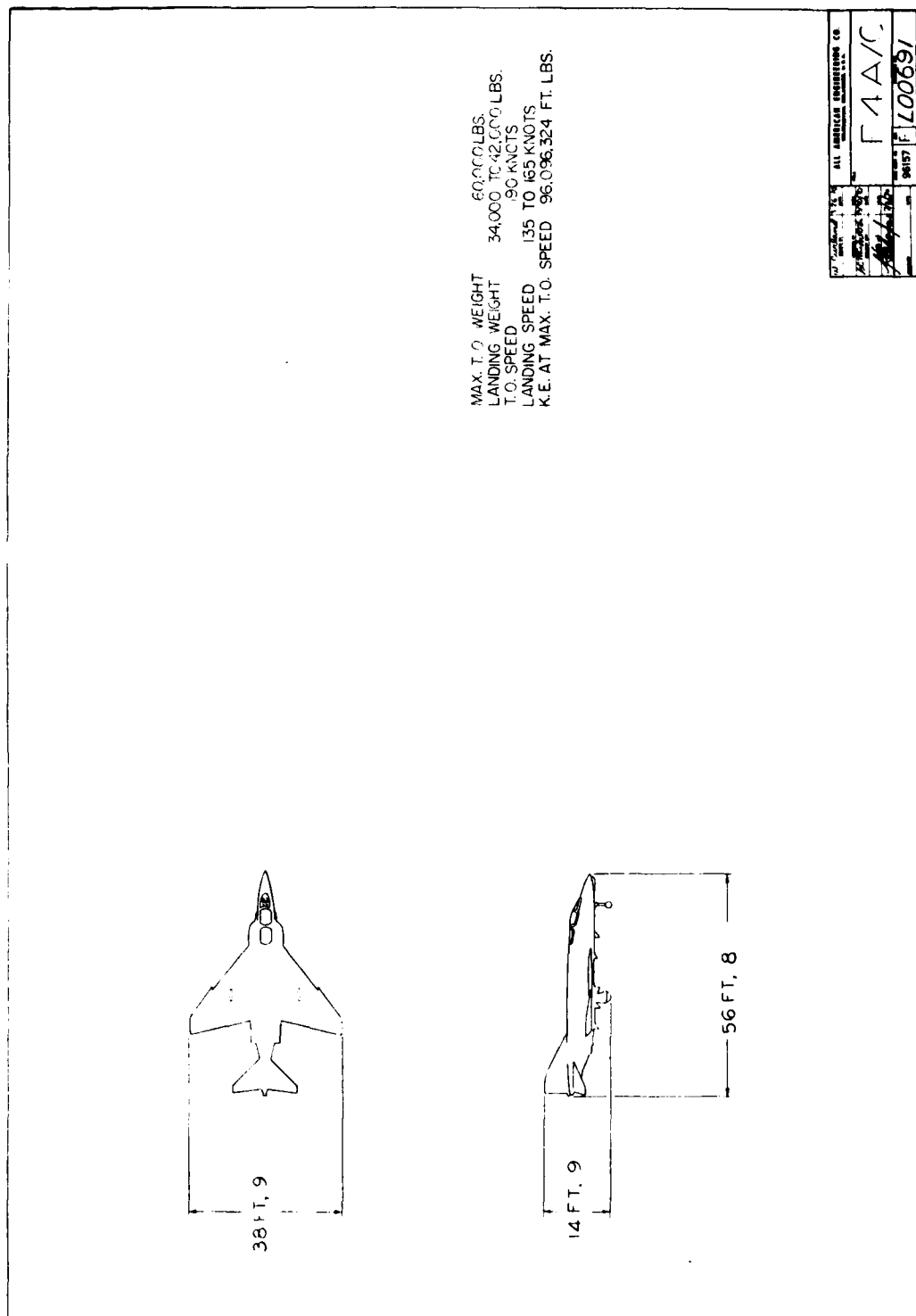
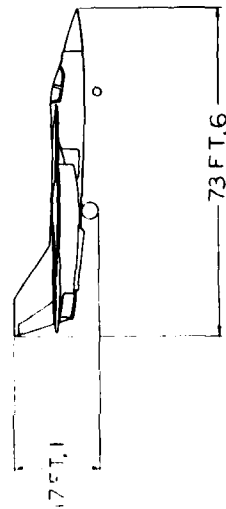
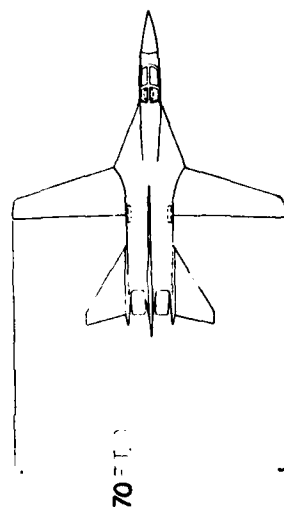


Figure 9. F-4 Aircraft



MAX. T.O. WEIGHT 125,000 LBS.  
 LANDING WEIGHT 57,000 LBS.  
 T.O. SPEED 170 KNOTS  
 LANDING SPEED 112 KNOTS  
 K.E. AT MAX. T.O. SPEED 160,271,456 FT. LBS.

UNIT	NO.	ALL	UNITED STATES AIR FORCE
MODEL			FB-111A/C
YEAR			1968
NO.			F 100698
DATE			11/2/68

Figure 10. FB-111 Aircraft

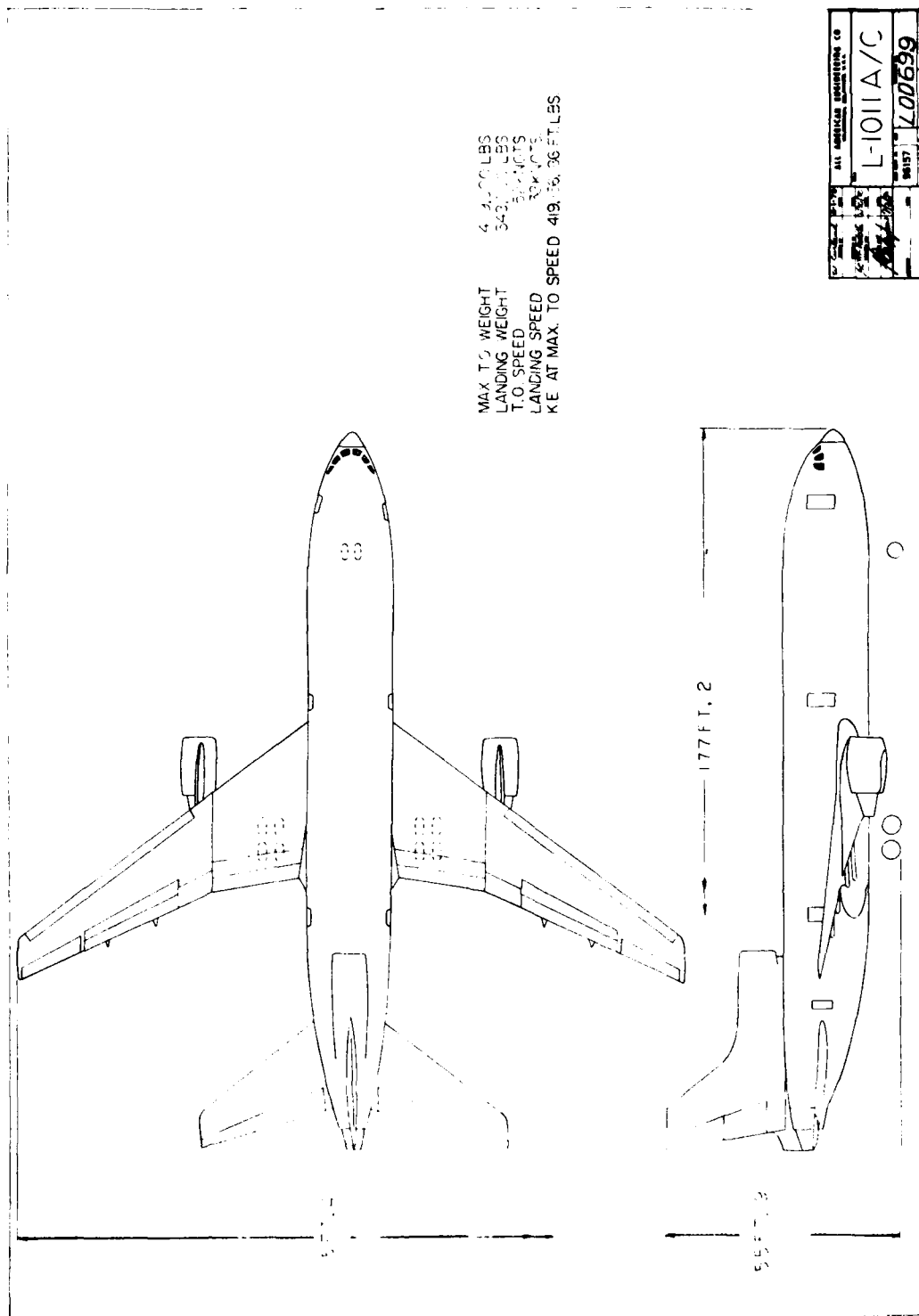


Figure 11. L-1011 Aircraft

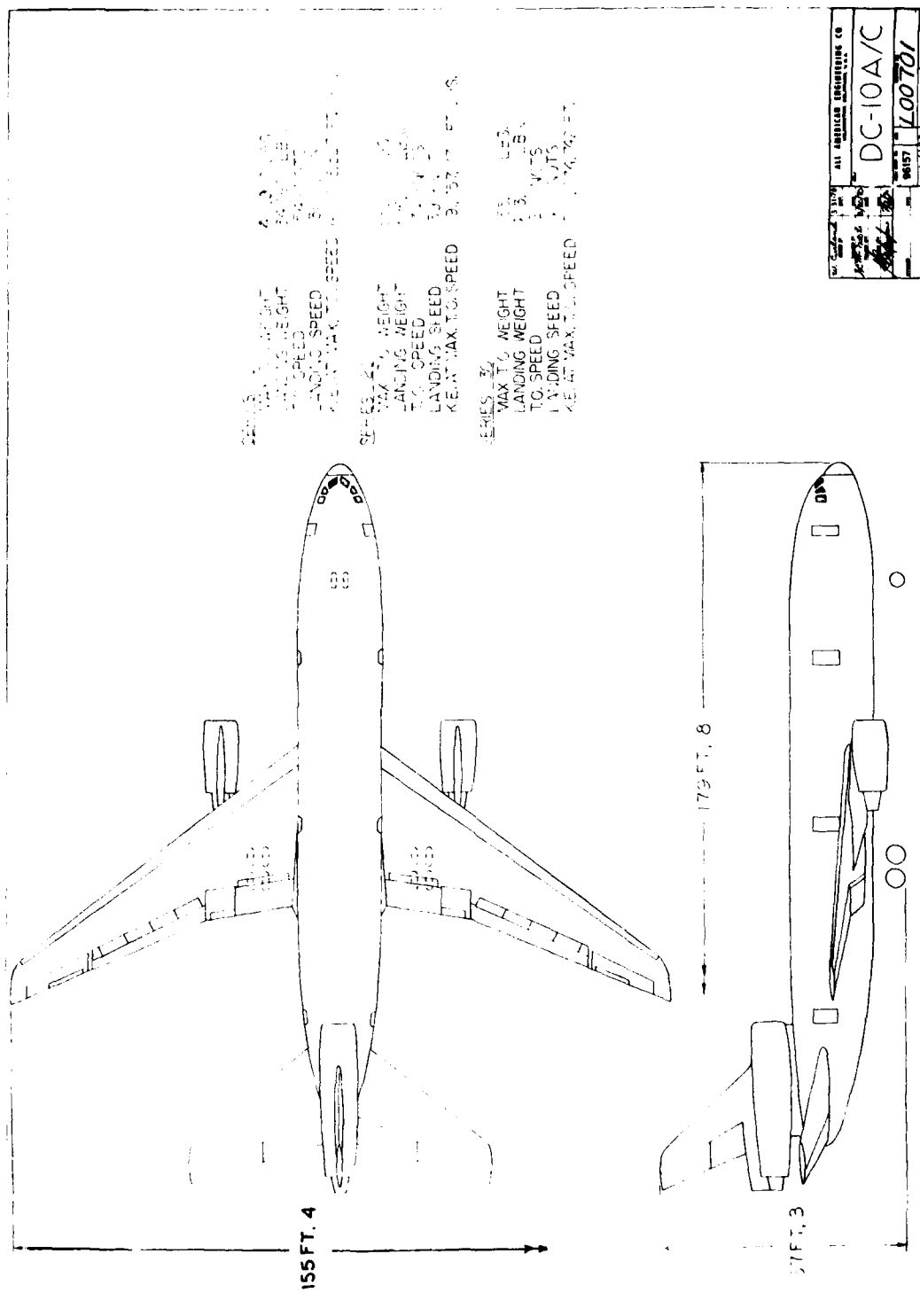


Figure .12. DC-10 Aircraft

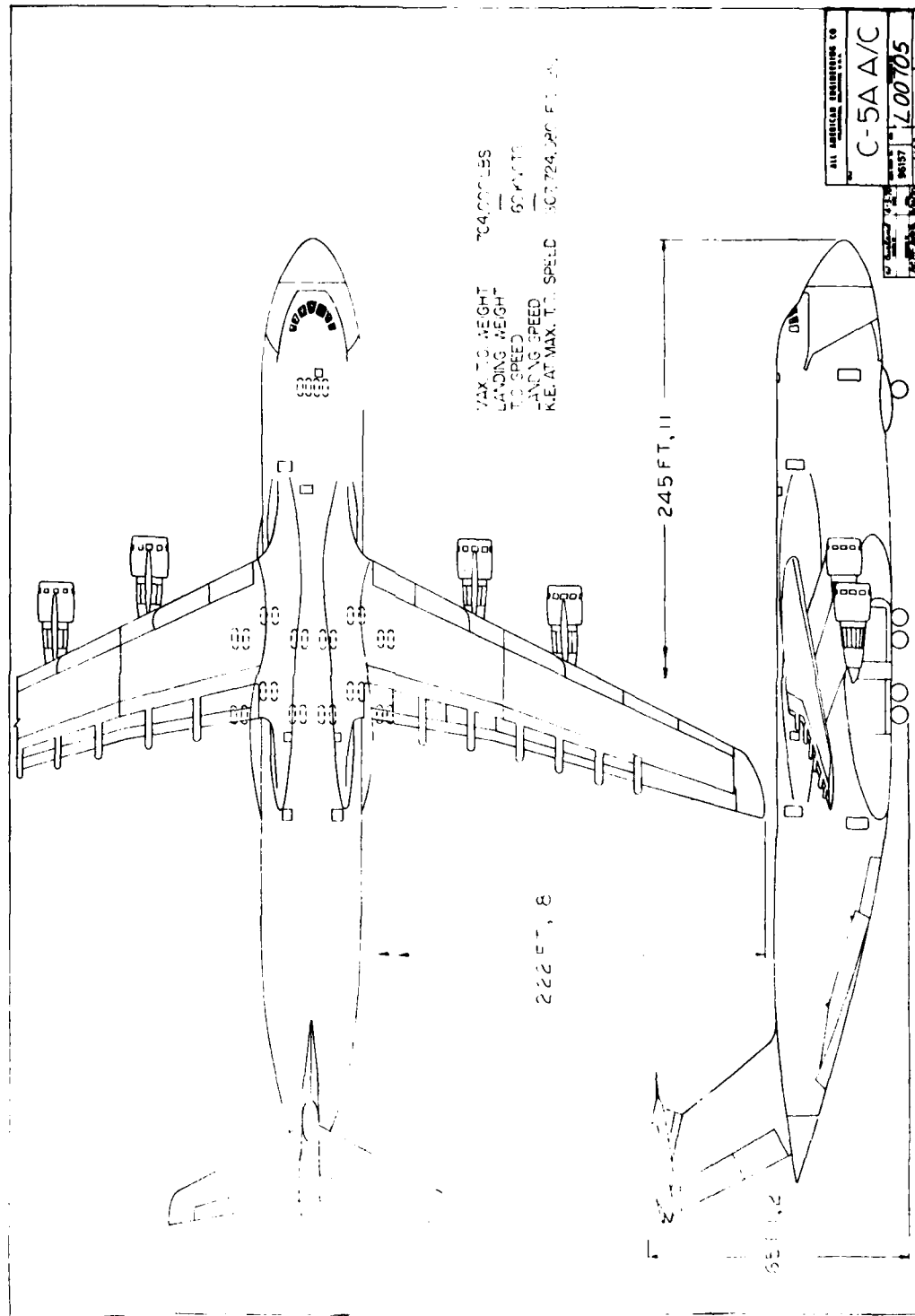


Figure 13. C-5A Aircraft

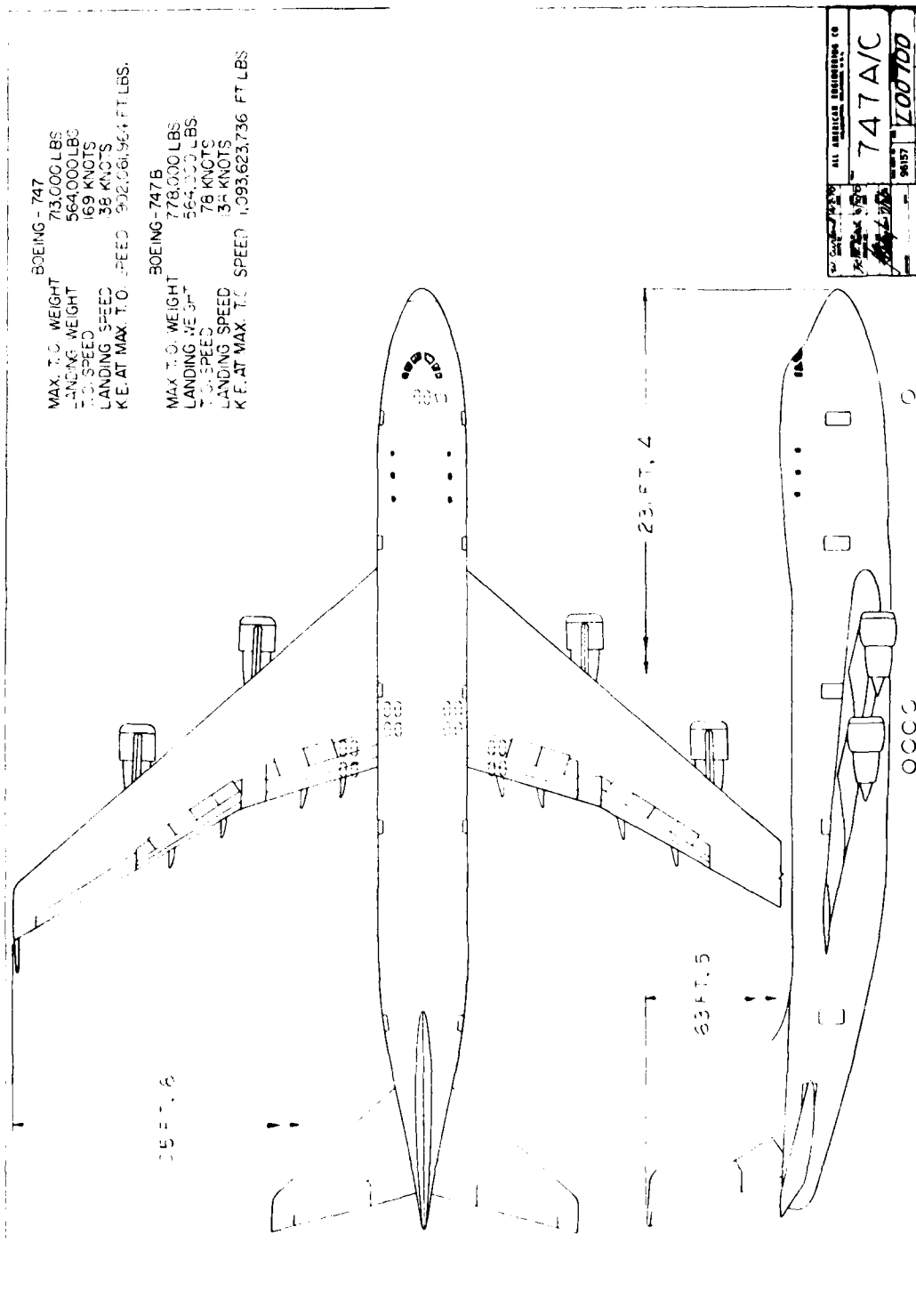


Figure 14. 747 Aircraft



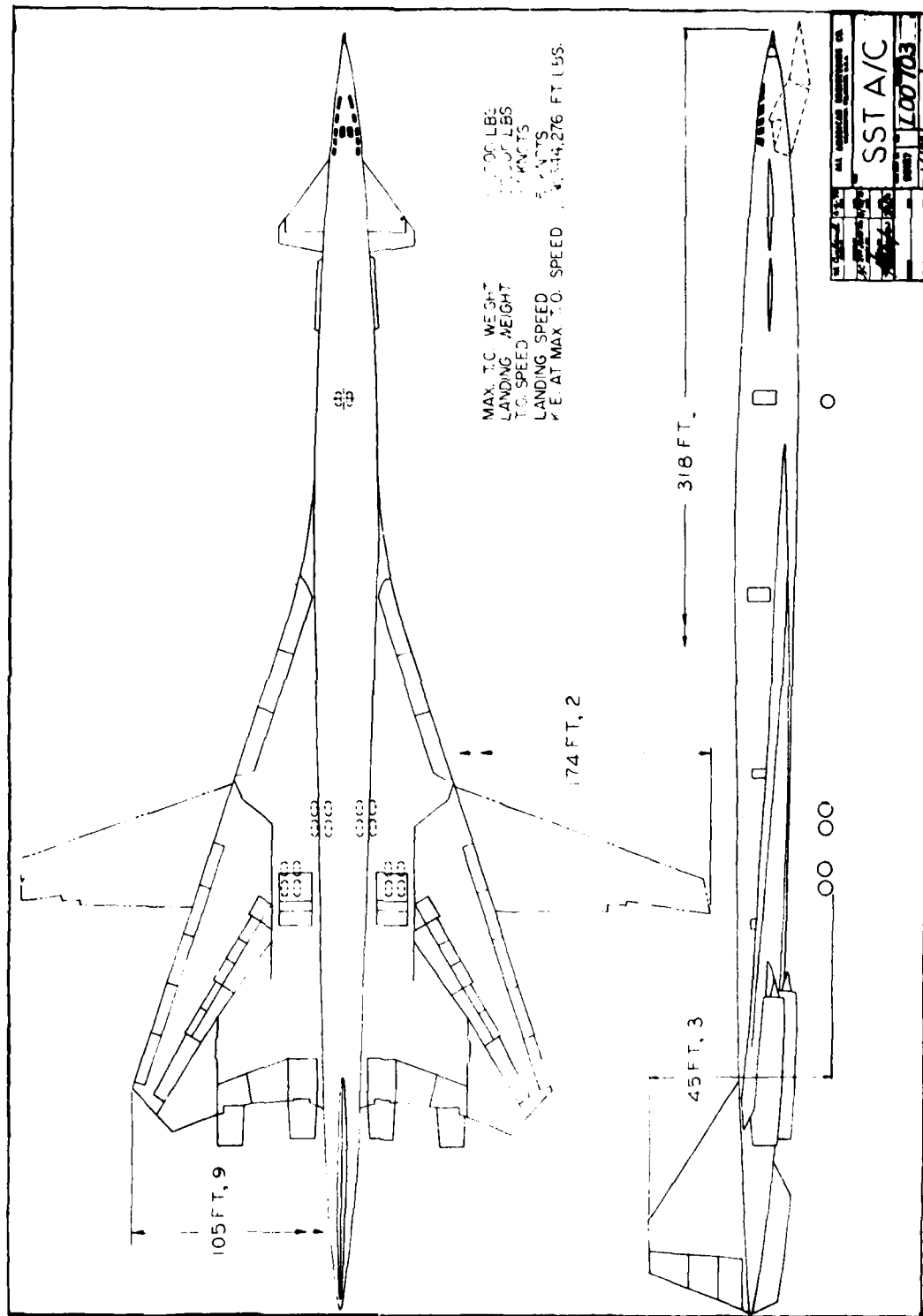


Figure 15. SST Aircraft

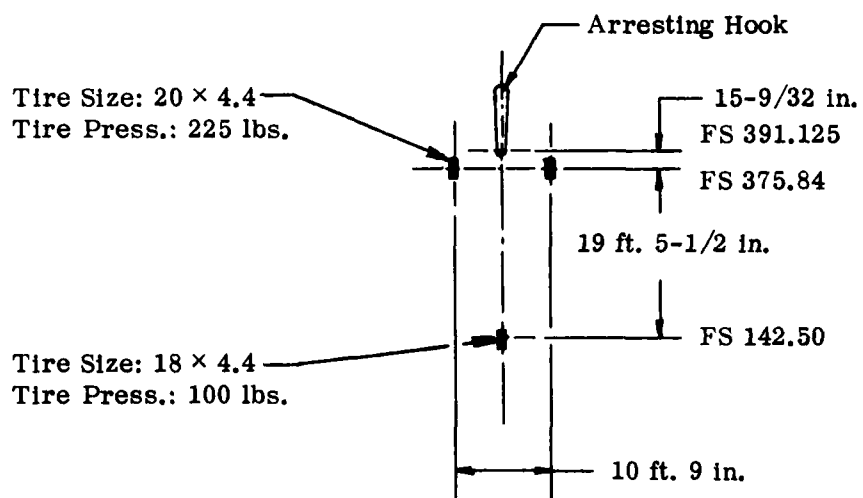


Figure 16. T-38 Aircraft Landing Gear Spacing, Tire Pressures, and Hook Location

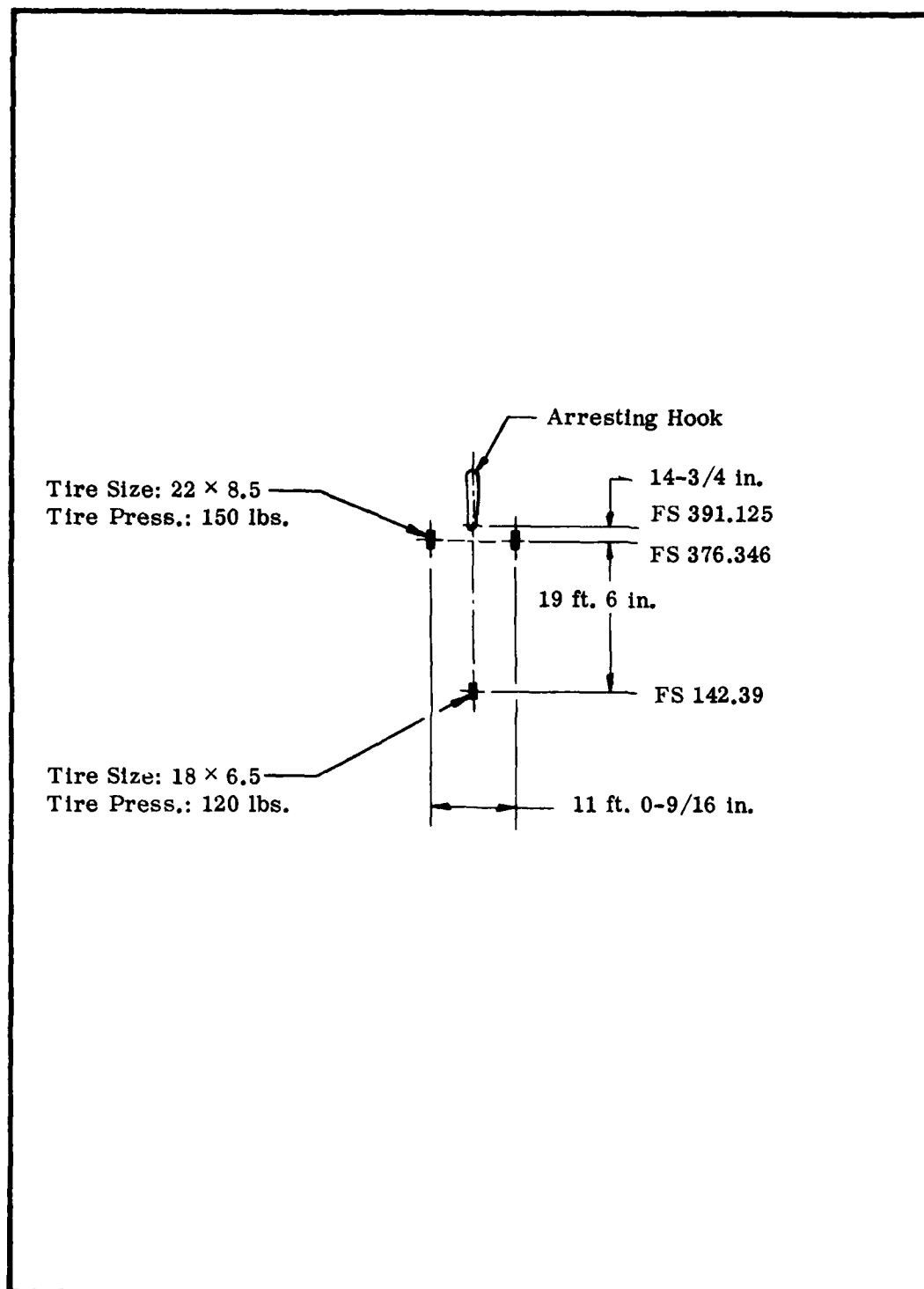


Figure 17. F-5B Aircraft Landing Gear Spacing, Tire Pressures, and Hook Location

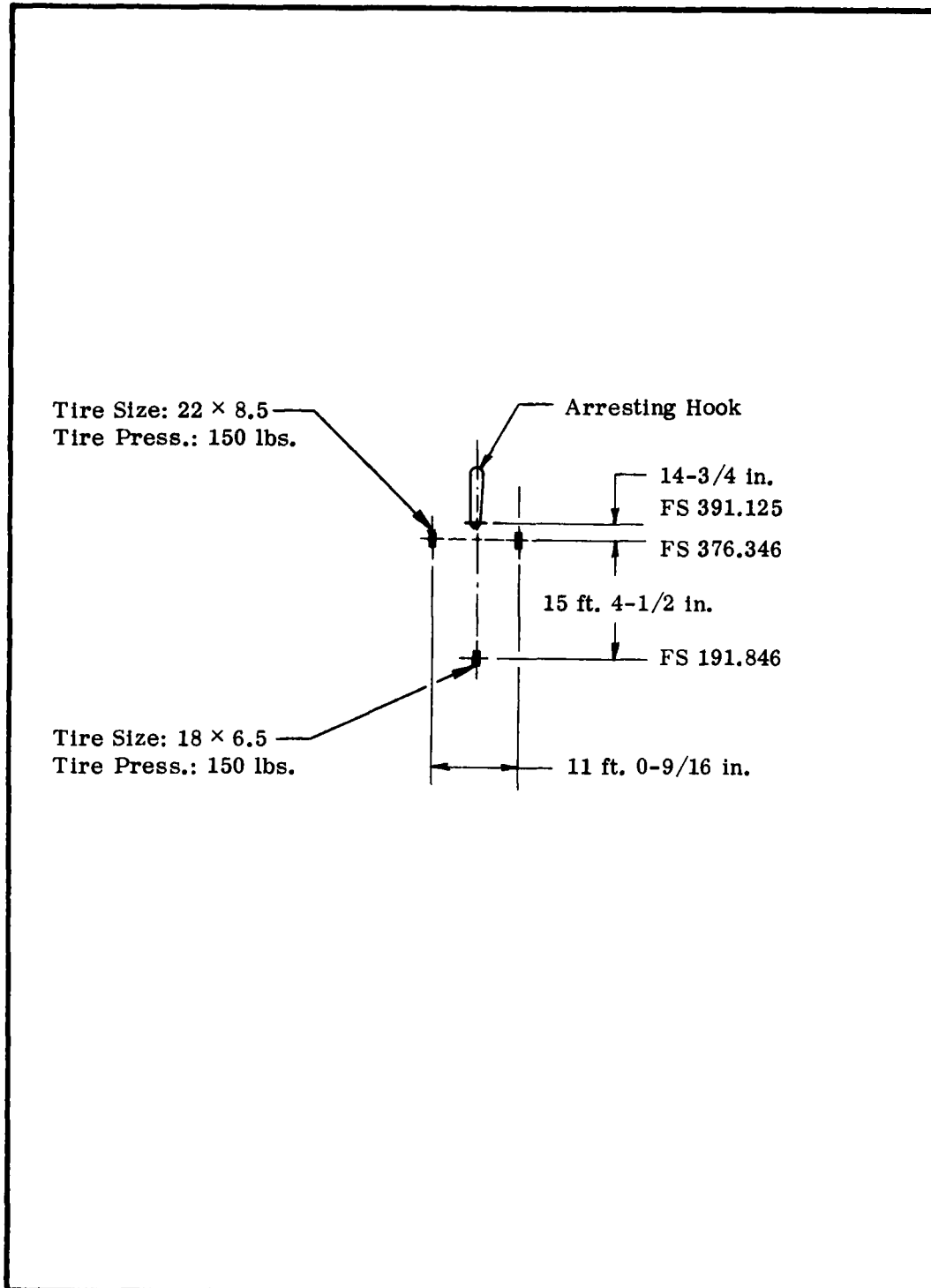


Figure 18. F-5A Aircraft Landing Gear Spacing, Tire Pressures, and Hook Location

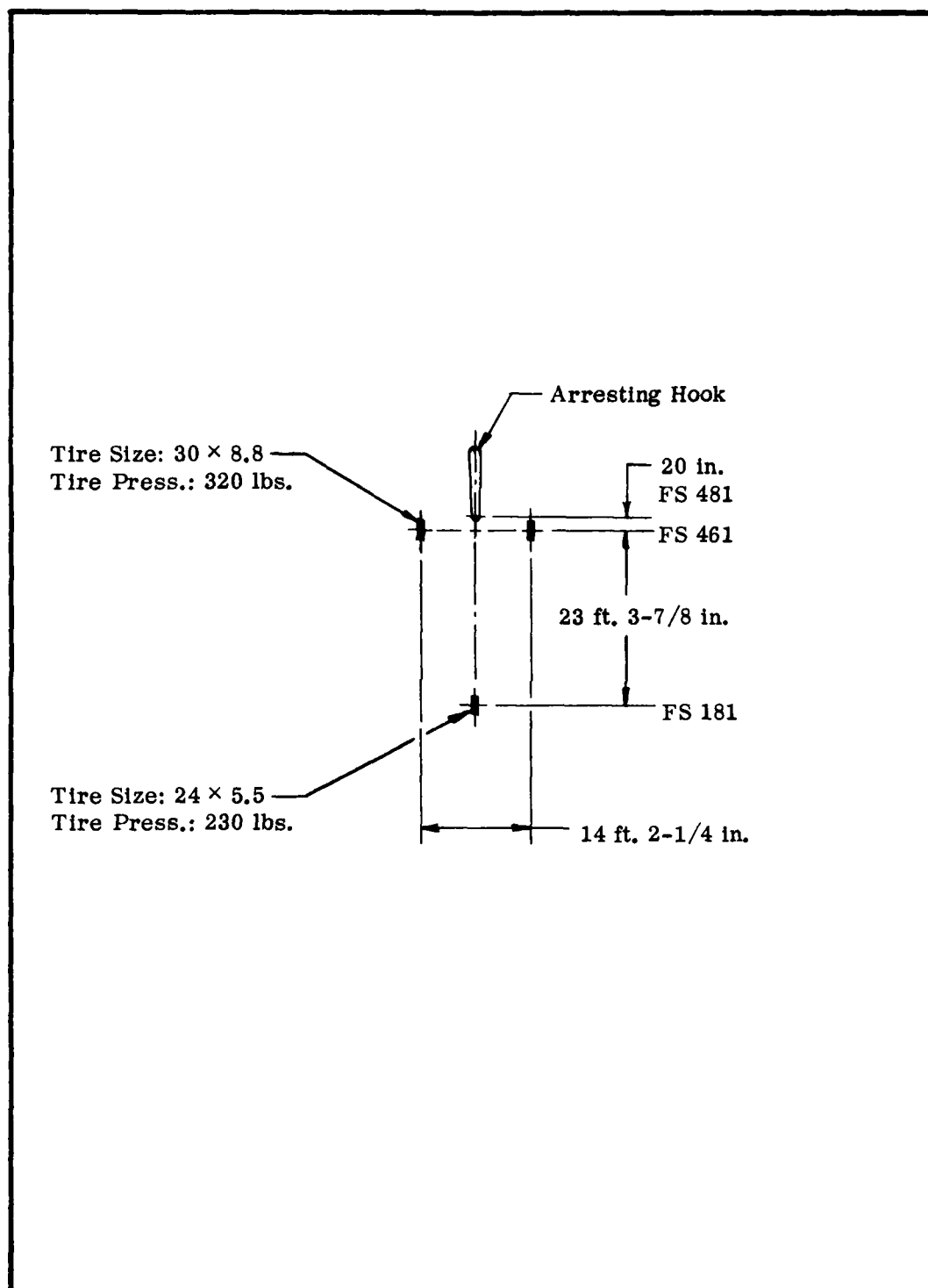


Figure 19. F-102 Aircraft Landing Gear Spacing, Tire Pressures, and Hook Location

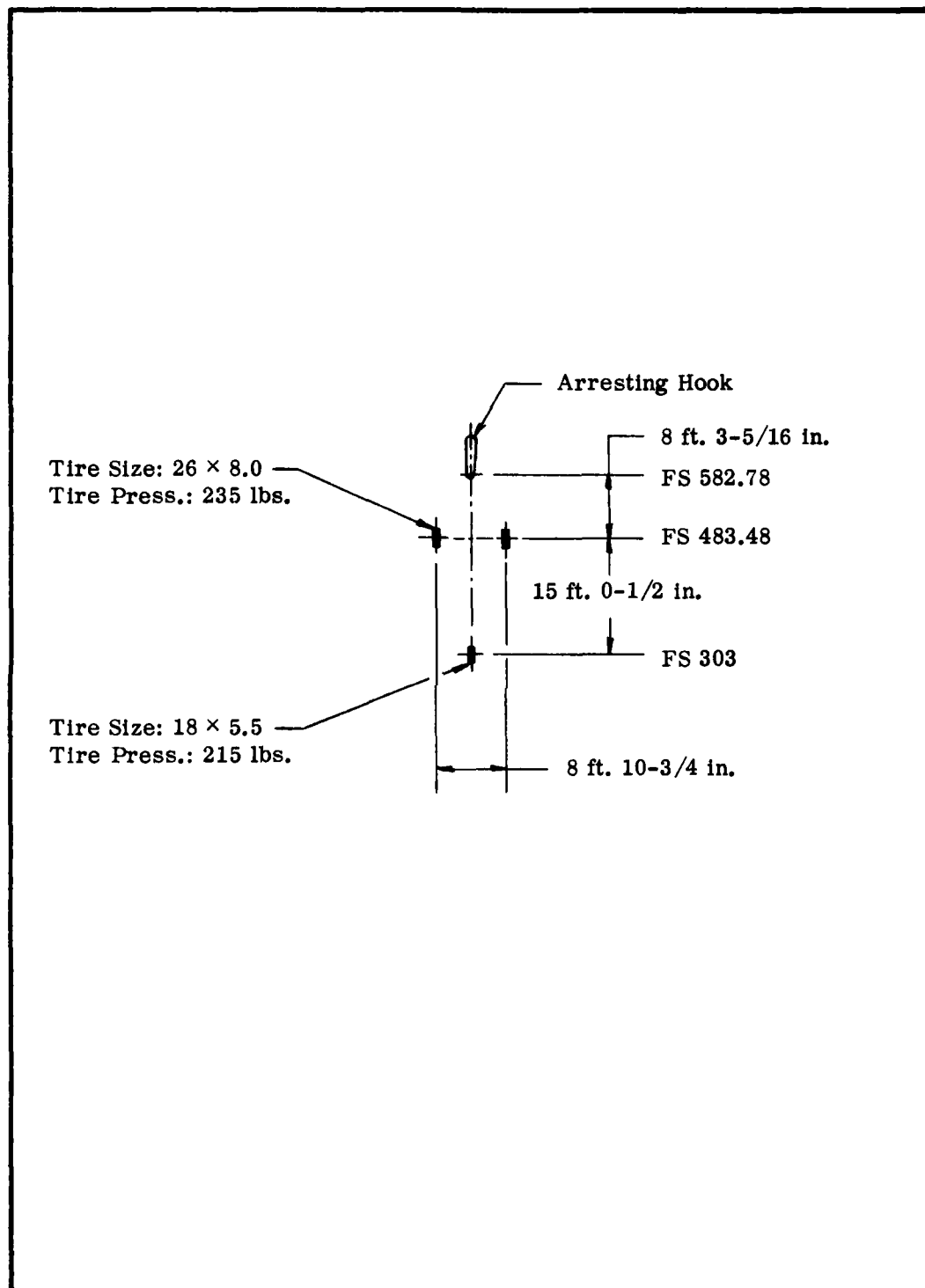


Figure 20. F-104 Aircraft Landing Gear Spacing, Tire Pressures, and Hook Location

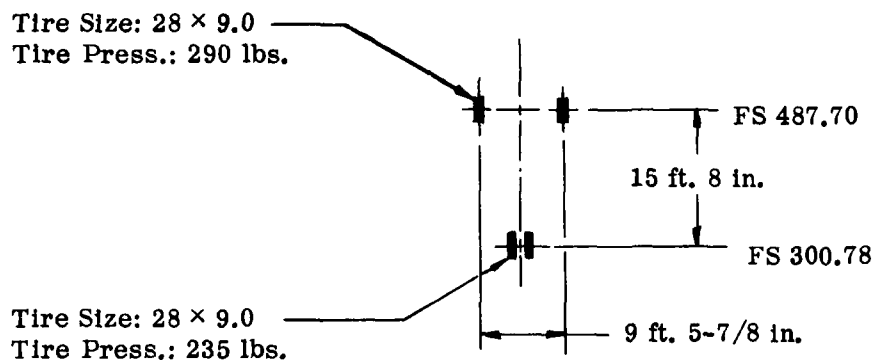


Figure 21. A-7D Aircraft Landing Gear Spacing, Tire Pressures, and Hook Location

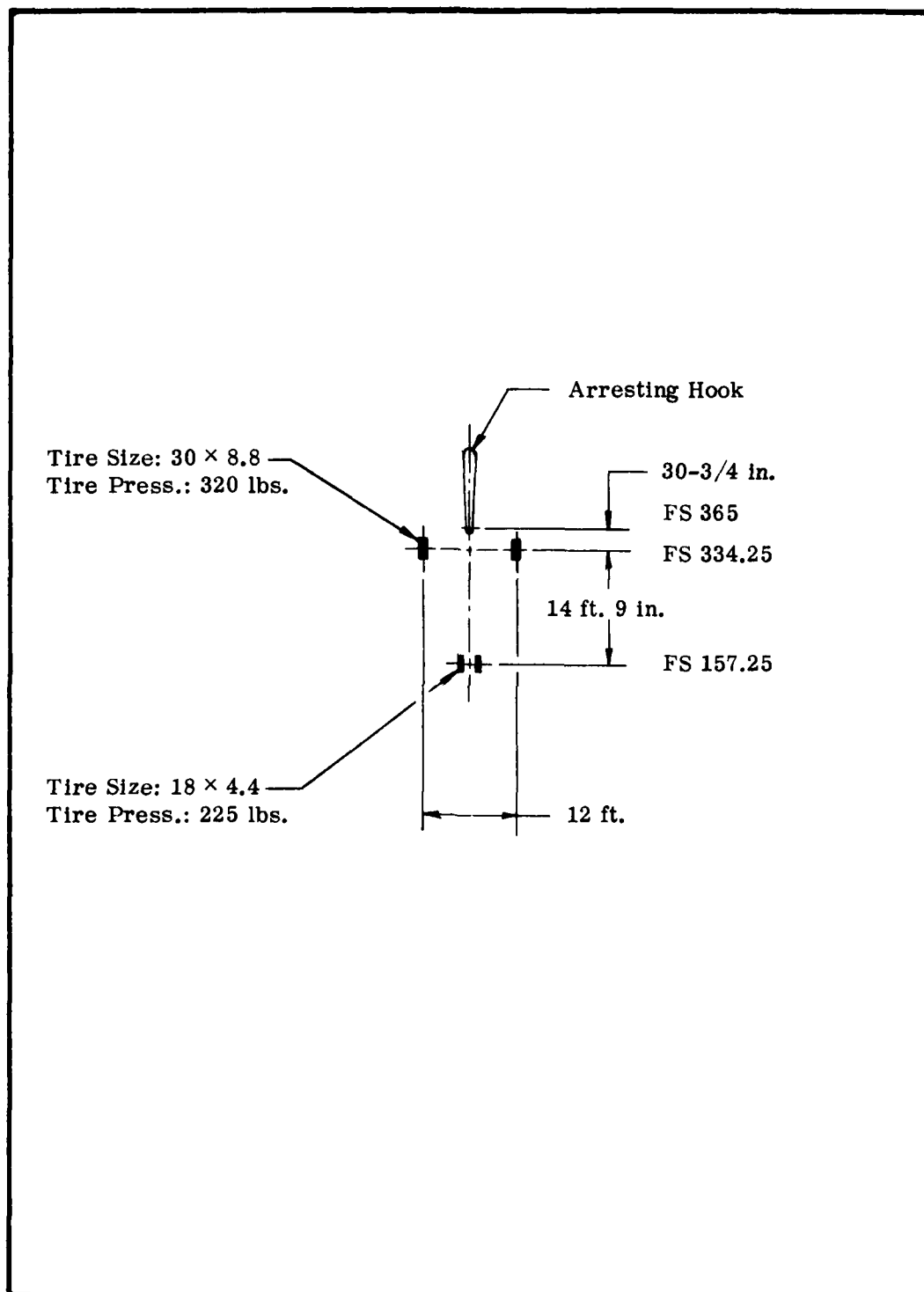


Figure 22. F-100 Aircraft Landing Gear Spacing, Tire Pressures, and Hook Location



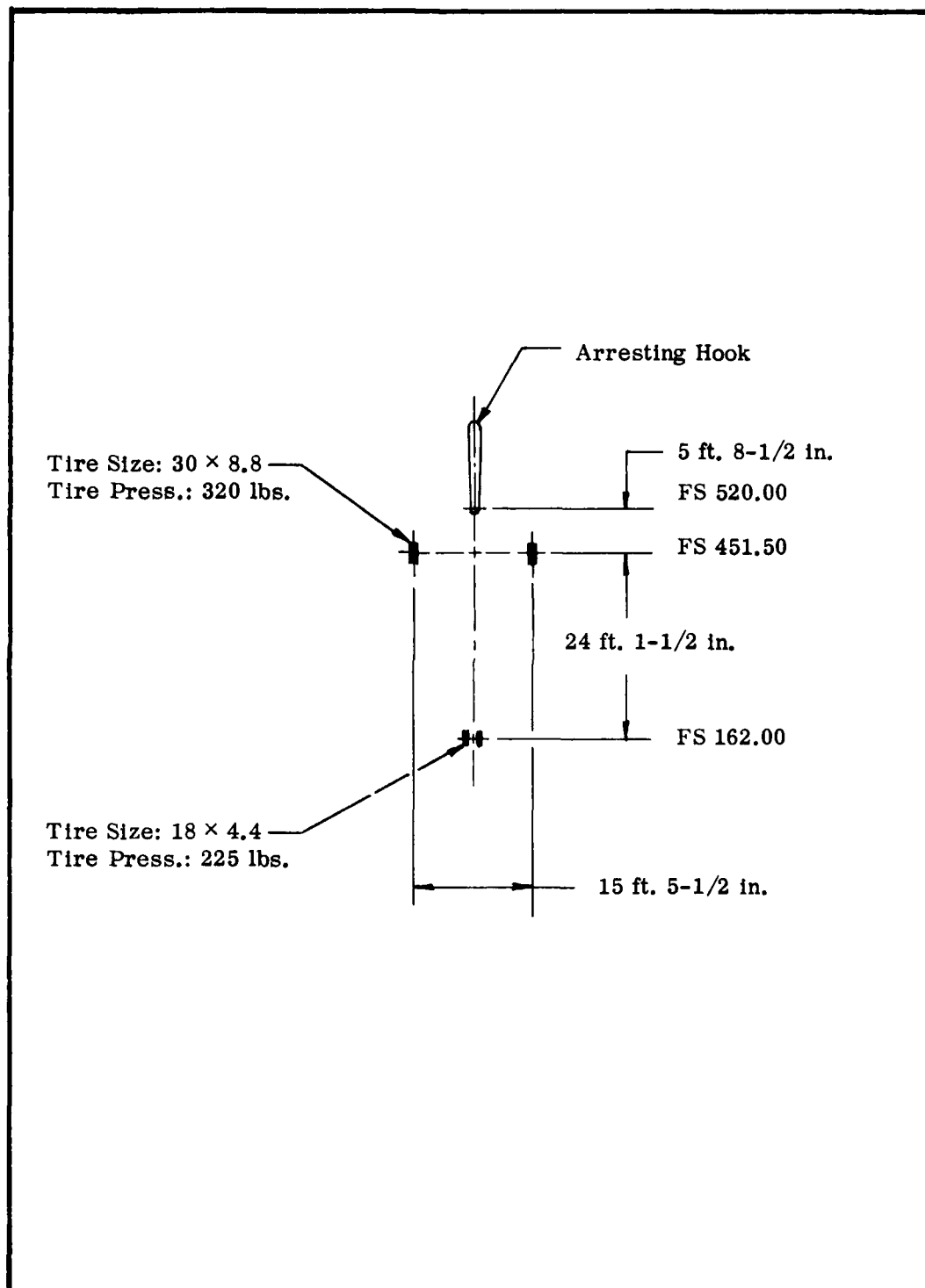


Figure 23. F-106 Aircraft Landing Gear Spacing, Tire Pressures, and Hook Location

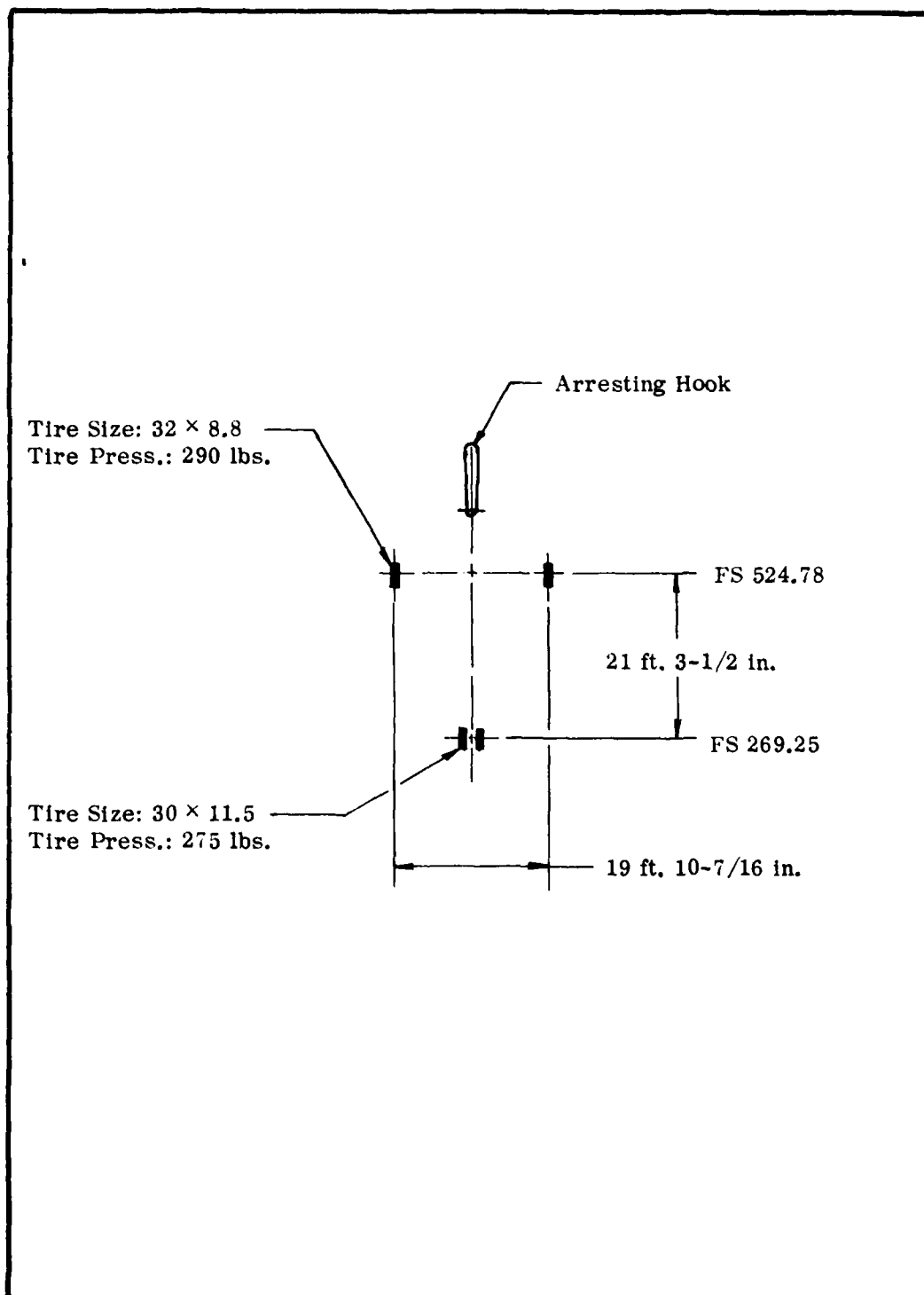


Figure 24. F-101 Aircraft Landing Gear Spacing, Tire Pressures, and Hook Location

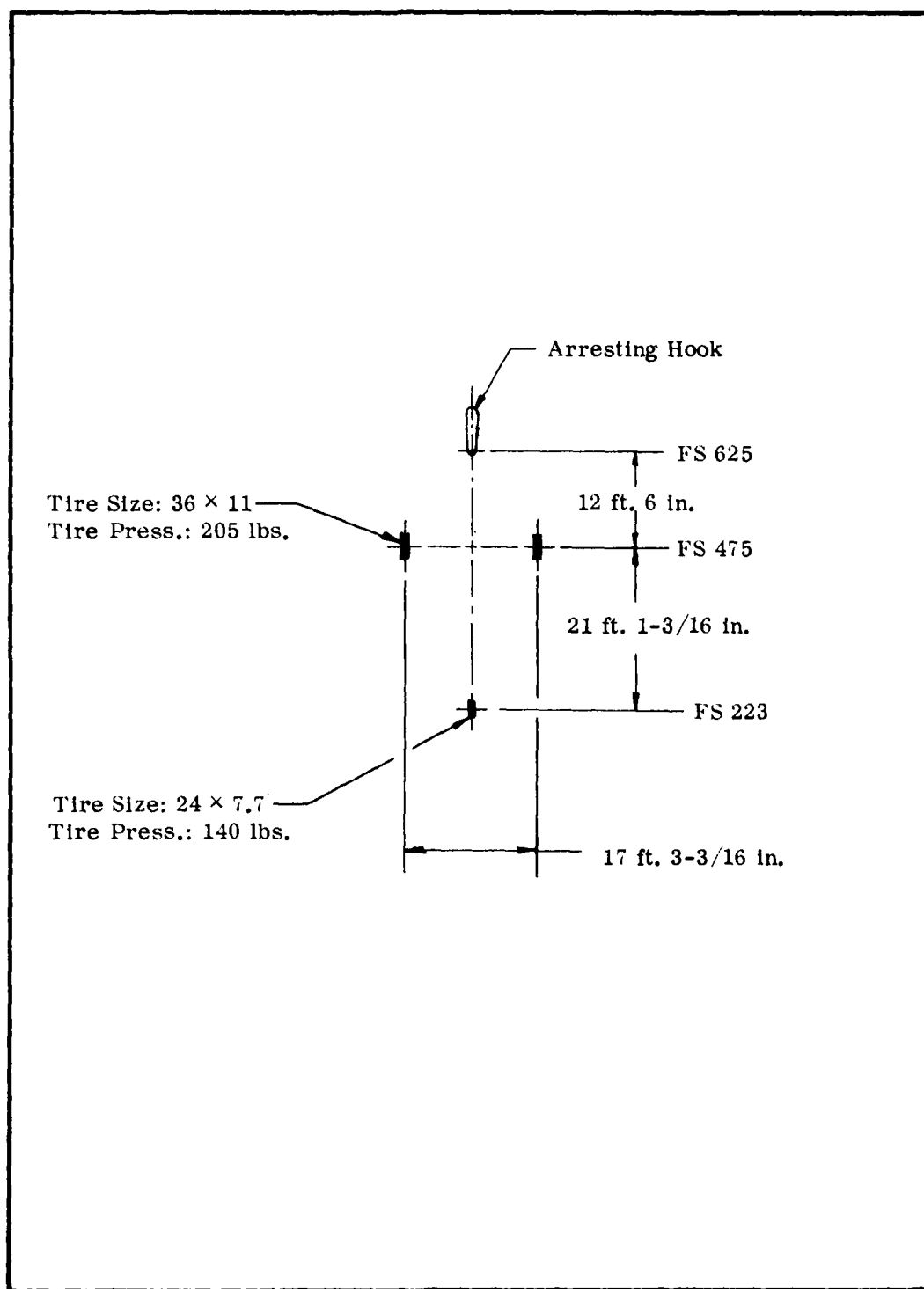


Figure 25. F-105 Aircraft Landing Gear Spacing, Tire Pressures, and Hook Location

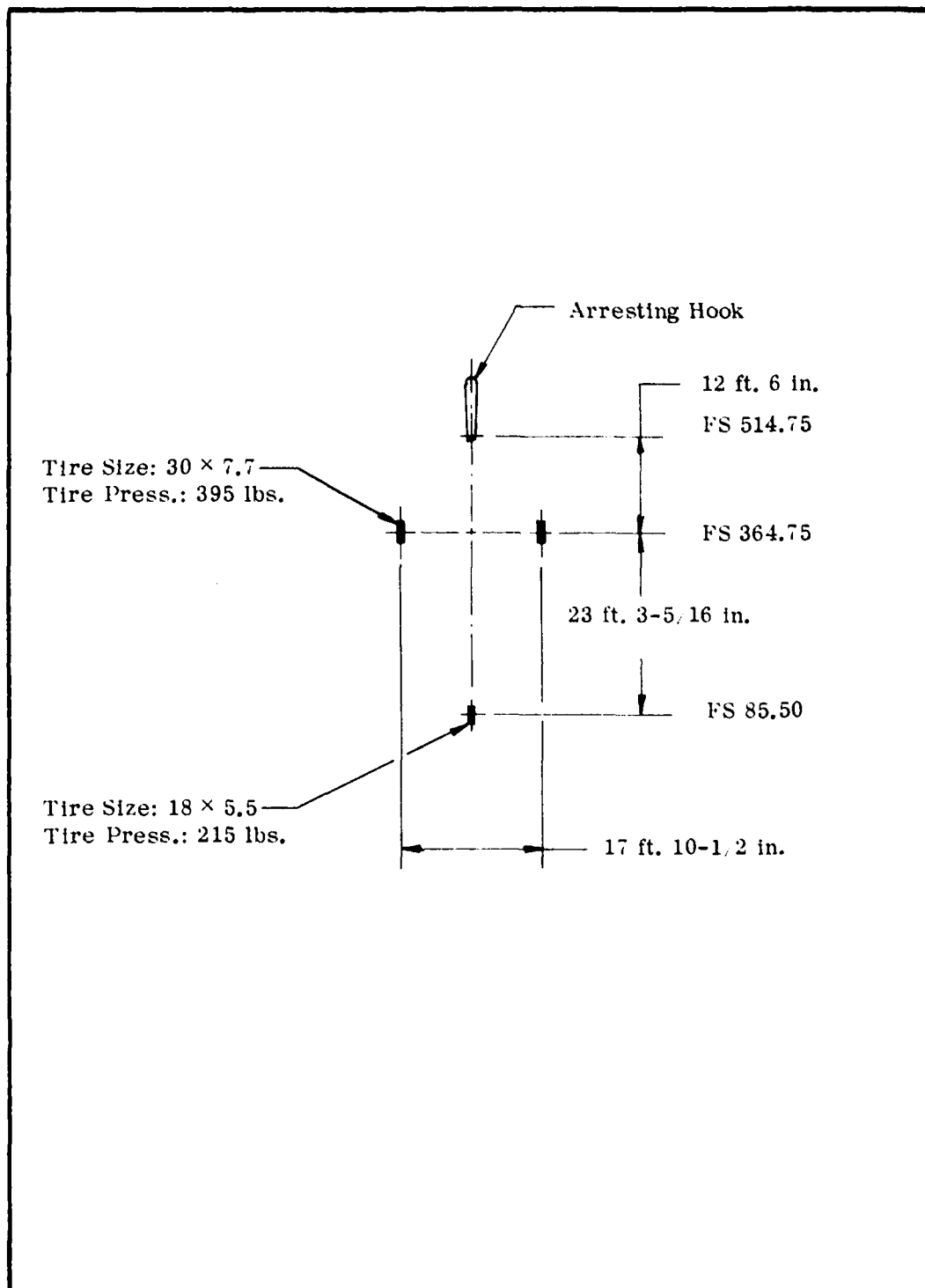


Figure 26. F-4 Aircraft Landing Gear Spacing, Tire Pressures, and Hook Location

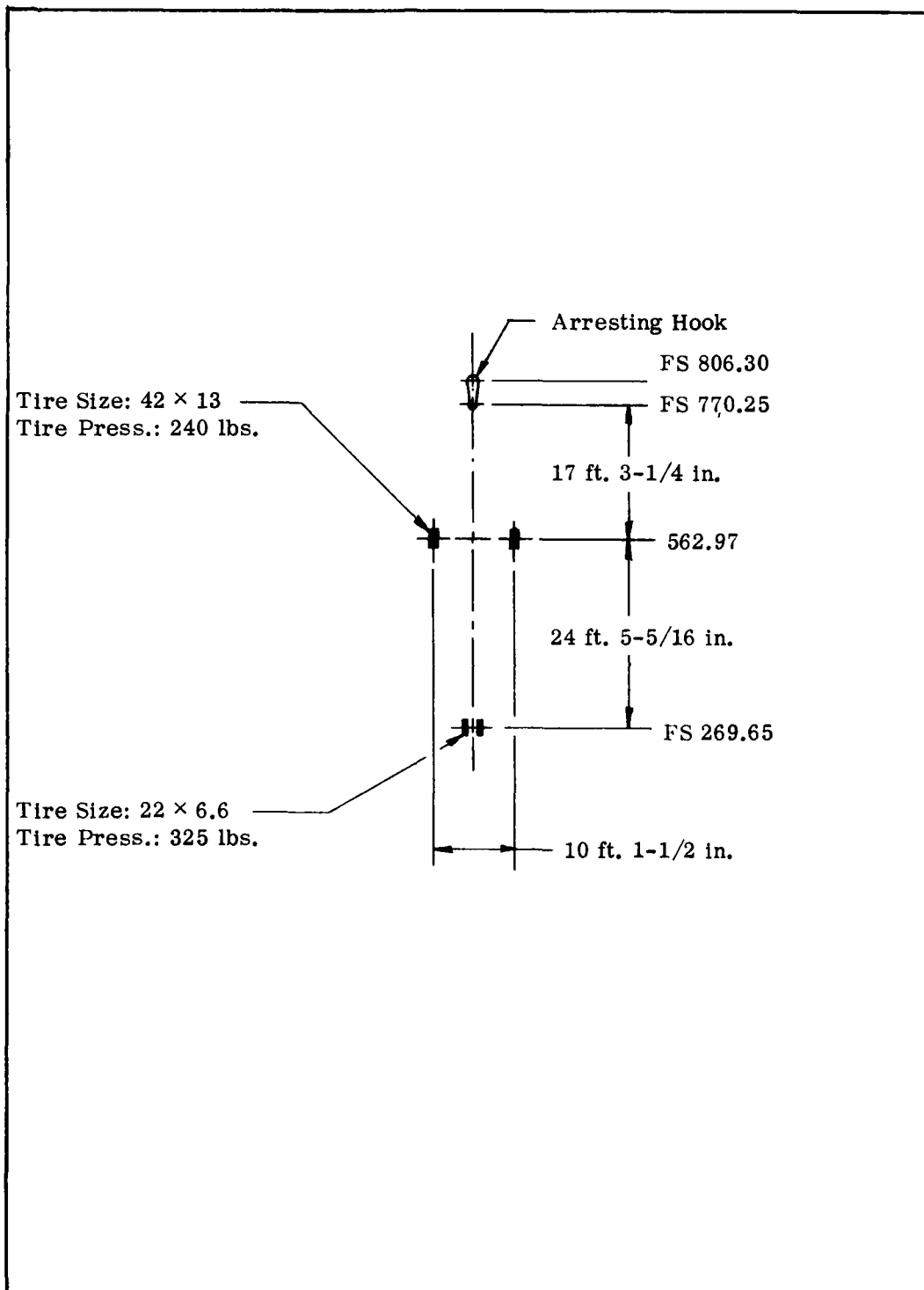


Figure 27. F-111 Aircraft Landing Gear Spacing, Tire Pressures, and Hook Location

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Figure 28. Proposed Supersonic Interceptor Aircraft Landing Gear Spacing,  
Tire Pressures, and Hook Location

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Figure 29. L-1011 Aircraft Landing Gear Spacing and Tire Pressures

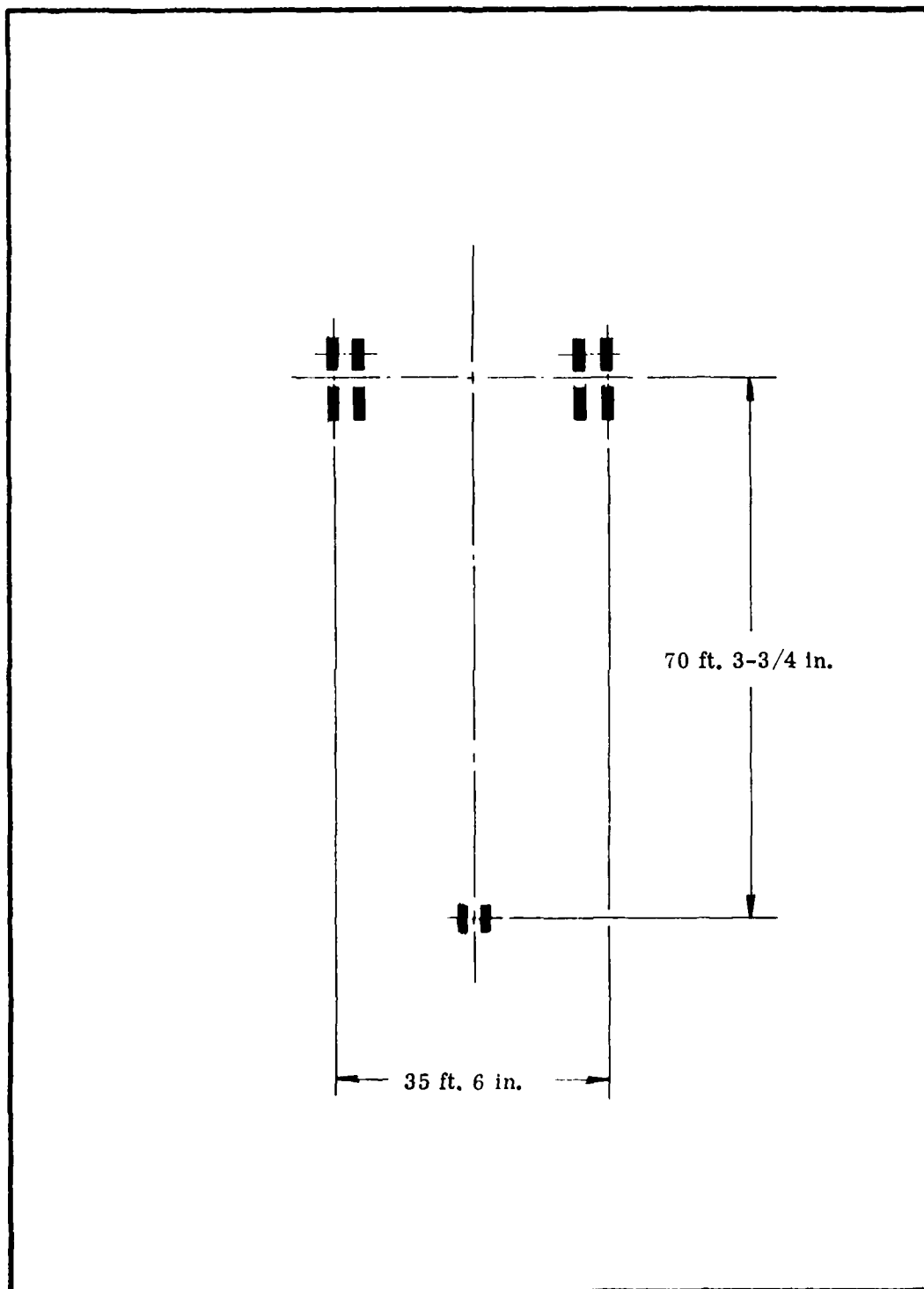


Figure 30. DC-10-10 Aircraft Landing Gear Spacing and Tire Pressures



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Figure 31. DC-10-20 Aircraft Landing Gear Spacing and Tire Pressures

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Figure 32. DC-10-30 Aircraft Landing Gear Spacing and Tire Pressures

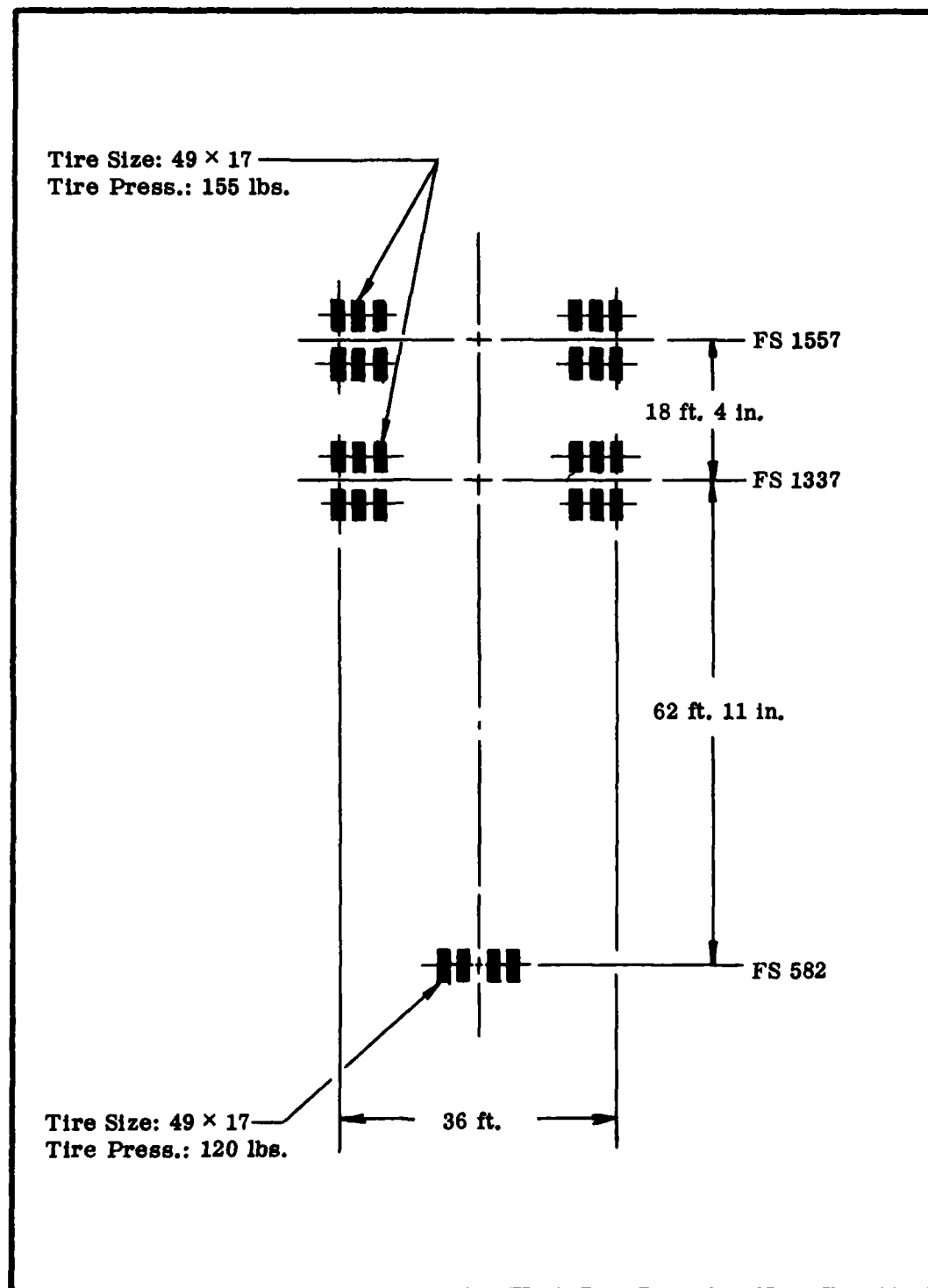
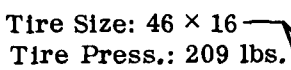


Figure 33. C-5A Aircraft Landing Gear Spacing and Tire Pressures



Tire Size: 46 x 16—  
Tire Press.: 165 lbs.

48

The information required to complete  
this page is not available.

Figure 35. 747B Aircraft Landing Gear Spacing and Tire Pressures

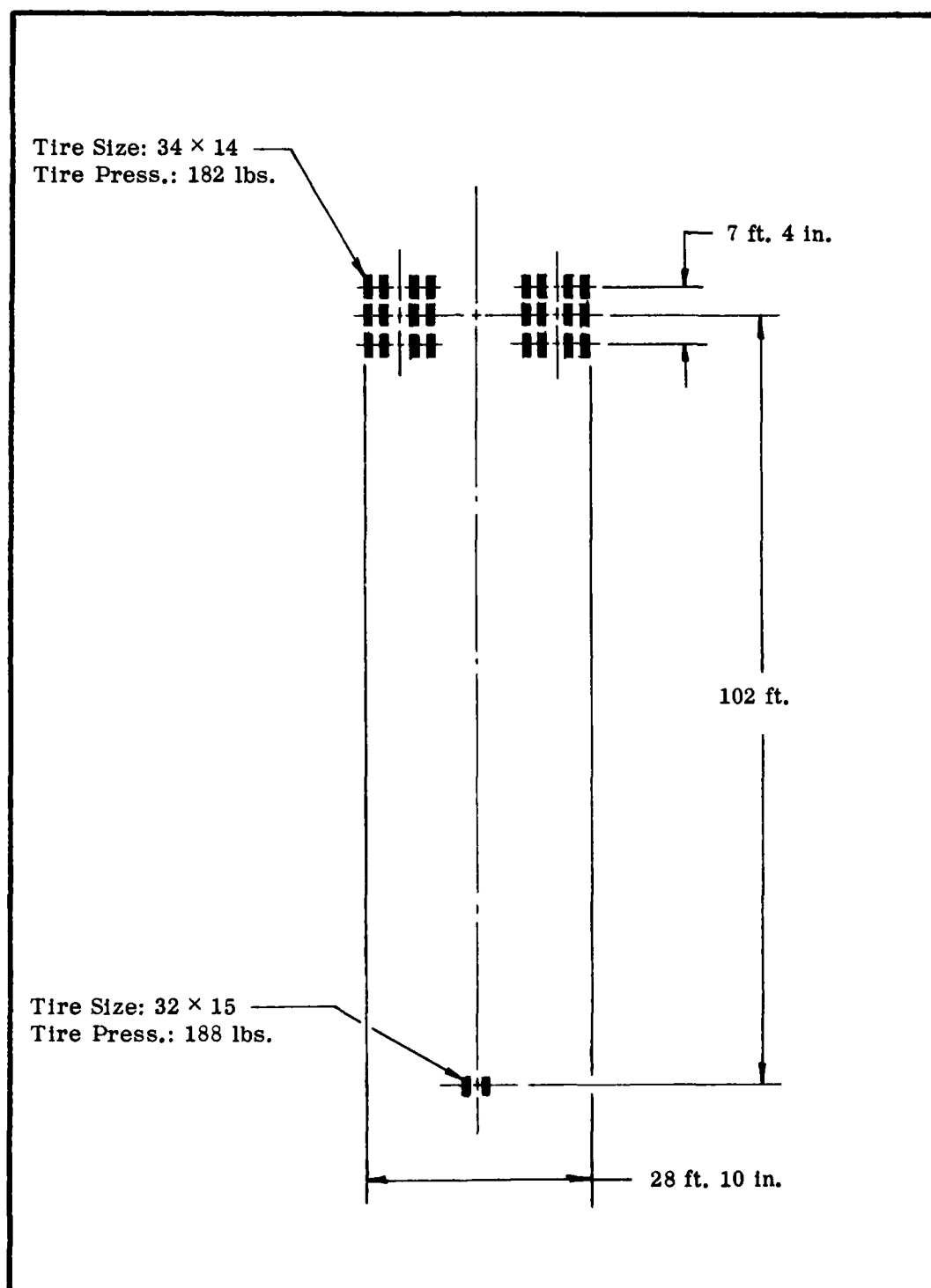
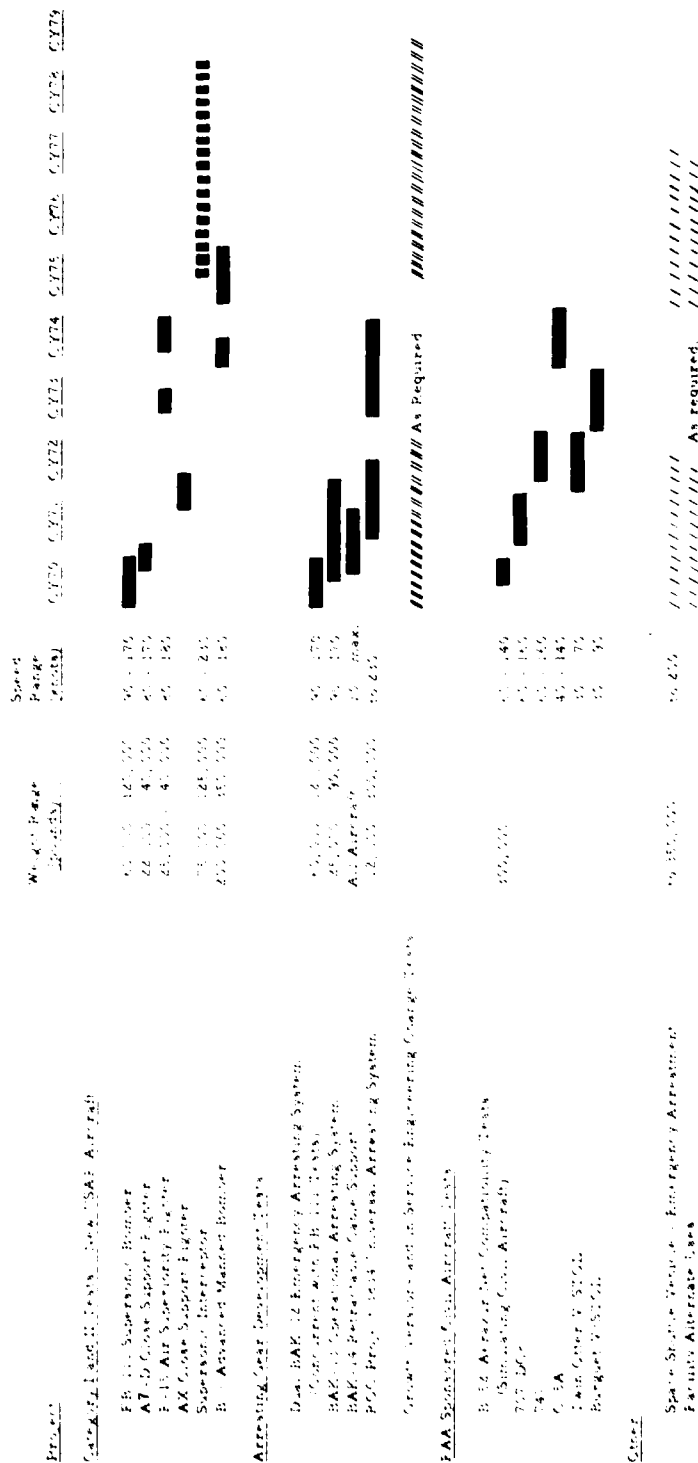


Figure 36. SST Aircraft Landing Gear Spacing and Tire Pressures

## SECTION IV

### REQUIRED CAPABILITY

Interviews were conducted with Wright-Patterson and Edwards AFB personnel who are in positions to know or objectively project the current and future tests that must be accomplished at Edwards. These test requirements are graphically displayed in the Projected Workload Chart, Figure 37, on the page following. This chart shows the Projected Projects, the type of testing required, the weight and speed range requirements, and the time interval over which the testing is to be accomplished. This chart represents the contractor's understanding of the work requirements as interpreted from cognizant Air Force personnel and is not to be considered a commitment on the part of any agency or command.



**Figure 37. AFFTC Projected Work Load Chart**



## SECTION V

### PROPULSION SYSTEMS

#### 1. OBJECT

The object of this section of the study is to determine the optimum method of accelerating a wheeled vehicle or vehicles to a given engaging velocity over a fixed distance into the arresting gear under test. All known practical means of propulsion are listed and compared. The criteria used for comparing one means with any other is as follows:

- a. Flexibility of varying the weight and speed of the test vehicle.
- b. Damage or loss from accidents or missed engagements.
- c. Ease of maintenance.
- d. Cost of operation and maintenance.
- e. Number of personnel and cost of facilities required for support.
- f. Compatibility with existing arresting gear test facility.
- g. Reliability.
- h. Safety.
- i. Cost of facilities.

#### 2. NON-OPERATIONAL SYSTEMS

The first step in the comparison was to group the systems into those which are operational and those which have not, for one reason or another, become operational. For purposes of this study, an operational system is defined as a system which performs on a reliable basis within its design energy limitations. Those systems which were non-operational and, therefore, would require considerable development time and money were eliminated from further consideration. A brief description of these non-operational systems as listed below can be found in Appendix II.

##### a. Reaction Jet Systems

- (1) Solid Propellant Jet, Air Ejector
- (2) Hot Water Rocket, POWARO

##### b. Catapult Systems

- (1) Pulley Tow, Jet Car Towing
- (2) Gas Turbine Compressor Piston, Cylinder Burner
- (3) Large Electric Motor Connected to Power Lines
- (4) Conventional Steam Power Plant, Turbine, Capstan Driven Cable

- (5) Linear Induction Motor
- (6) Internal Combustion or Steam Zipper
- (7) Reeved Cable, Hydraulically Driven, Hydropneumatic Accumulators
- (8) Compressed Air, Piston Cylinder, Pneumatic Accumulators
- (9) Compressed Air, Piston Cylinder, Burner
- (10) Flywheel Clutch, Capstan Driven Cable
- (11) Water Turbine Driven Cable Drum

c. Exhaust Augmentation System

- (1) Radial Inflow Turbine, Ground Geared
- (2) Radial Inflow Turbine, Propellor Geared
- (3) Ejection Turbine

### 3. OPERATIONAL SYSTEMS

Those systems which are operational include (1) a rocket powered car, (2) catapults, and (3) a turbojet engine car. There are three known catapults which are considered to be operational. These are the steam catapult as developed by the Navy and used operationally on board aircraft carriers, a flywheel catapult developed by E. W. Bliss Company for the French government and the CE series of catapults developed by this contractor for the Marine Corps.

a. Rocket Car

Solid propellant rockets were considered first. These units are highly reliable and have been in use operationally for many years throughout the world. IATO units, for example are used to launch Firebee and other target drones as well as assist aircraft in take-off. These units are relatively high in cost at \$1100.00 each. Using activities, however, have from time to time in the last decade contacted contractors engaged in the launching field in an attempt to provide a less costly system for launching drones. Presumably the research and development aspects of proposed systems were sufficient to discourage the funding thereof. Other solid propellant rockets have been utilized to launch a combat configured fighter aircraft from zero length launchers at a nominal cost of \$1.00 per pound of thrust or about \$150,000.00 per launch.

Liquid fuel rockets were also considered as a means of propulsion. This means, however, liquid fuel was considered less seriously than the solid propellant method due to the inherent additional complexity of the liquid fuel which require valves, tanks and plumbing not required with the solid fuel rockets. Reference is made to Appendix I which contains copies of the inquiry letter to three major rocket vendors and the replies received. It should be noted that the two vendors who replied indicate the cost of the rockets to be disproportionately high for the ultimate intended purpose.

Another possibility that exists when rocket power is considered is the use of surplus Air Force and other service rockets which have been deemed so by such factors as exceeding their specified shelf life. These would be available at no or little cost; however, the intended user would have no control over the availability of these surplus items and would be in a helpless position to make plans for future long term testing.

b. Catapults

(1) Steam Catapults

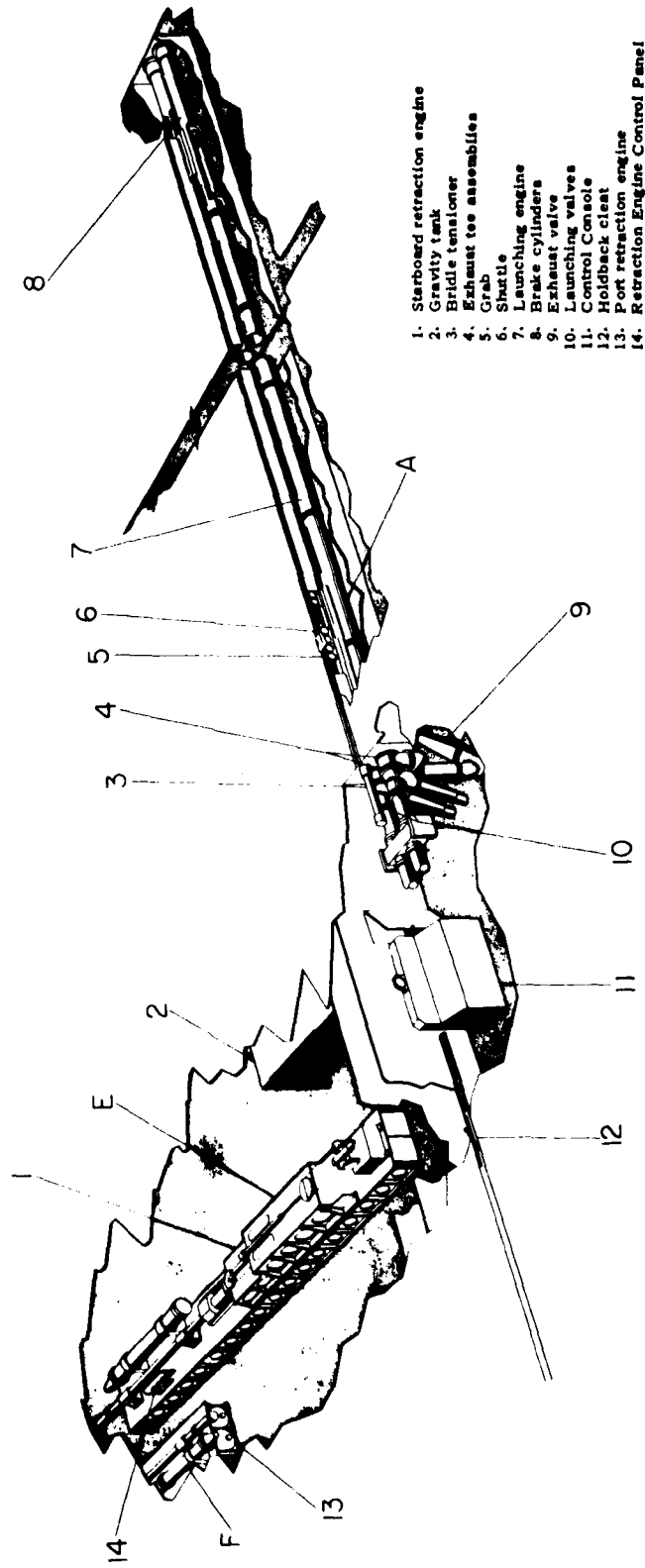
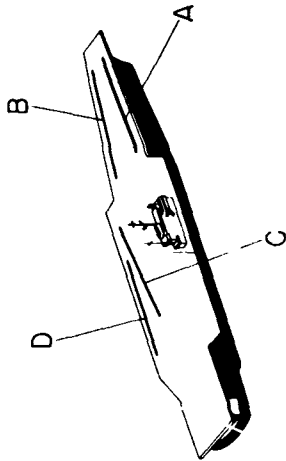
The steam catapult general arrangement as shown in Figure 38 is approximately 300 feet long and as a minimum modification would require an increase in the available launch stroke to accommodate the energy levels which the Air Force will eventually be considering. This modification, of course, would require development time and money. In addition, the utilization of a steam catapult would add a steam generating plant to the existing test facility at Edwards Flight Test Center. This additional facility is a costly item of such a magnitude that the steam catapult is eliminated as a serious candidate for the deadload propulsion system. In addition to the initial facility cost, operating costs are a prime factor. The average operating costs for steam generation at the Lakehurst facility for the intermittent operation of two steam catapults is approximately \$300,000.00 per fiscal year.

(2) Flywheel Catapult

The flywheel catapult shown schematically in Figure 39, manufactured for the French Government by E. W. Bliss Company is a stored energy system. It consists of one turbo shaft engine, clutch, flywheel, second clutch, reducing gearbox, tape storage drum, nylon tape as a towing medium, and a shuttle. The tape is reeved from the storage drum, through a fairlead tube and turn sheaves, along a guide track and attached to the shuttle at the battery end of the launch stroke. The shuttle is restrained in the guide track and trails a steel cable stored on and attached to a drum. A brake on the cable storage drum brings the system to a stop at the end of the launch stroke. A diesel engine is utilized to rewind the cable on the drum and thereby reset the tape and shuttle for the next launch.

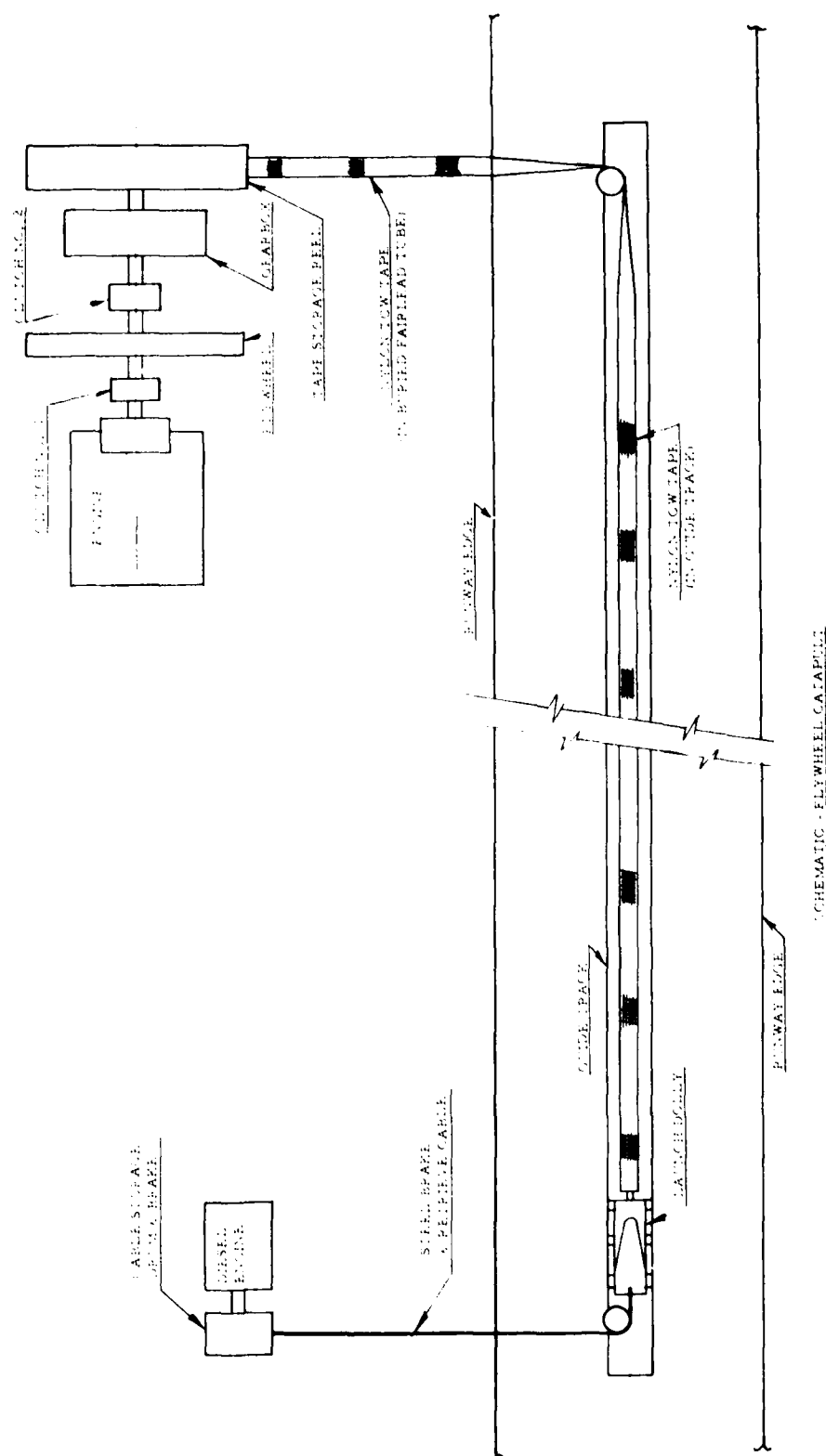
In operation both clutches are disengaged and the engines started. Clutch one is then engaged and the flywheel is brought up to operating speed. Clutch one is then disengaged uncoupling the engines from the flywheel making it a free rotating mass. To launch the deadload the second clutch is engaged coupling the flywheel to the tape storage reel through the gearbox. The energy stored in the flywheel is translated as torque to the tape reel winding tape on the reel thus causing tape tension or tow force. This force breaks a holdback fitting and accelerates the deadload to the desired velocity. A programmed brake on the cable

A	NO 1 CATAPULT
B	NO 2 CATAPULT
C	NO 3 CATAPULT
D	NO 4 CATAPULT
E	NO 1 CATAPULT RETRACTION ENGINE
F	NO 2 CATAPULT RETRACTION ENGINE



1. Starboard retraction engine
2. Gravity tank
3. Bridle tensioner
4. Exhaust tee assemblies
5. Grab
6. Shuttle
7. Launching engine
8. Brake cylinders
9. Exhaust valve
10. Launching valves
11. Control Console
12. Holdback cleat
13. Port retraction engine
14. Retraction Engine Control Panel

Figure 38. General Arrangement C-13 Steam Catapult



**Figure 39. Flywheel Catapult Schematic**

storage drum is used to stop the shuttle, launch tape and rotating parts at the end of the launch cycle. The system is then retracted by the diesel engine for the next launch. One catapult of this type has been procured by the French government and has been utilized to launch deadloads to test arresting gear systems in that country. The original fixed price for the development and delivery of the hardware was relatively low, i.e., in the order of \$350,000. In the interim, catastrophic failures and other problems have increased the total investment to over \$2,000,000. In the past, design studies conducted by this contractor have indicated that the major possible problem with this system could be with the inherent high capacity clutches which are required to transmit the torque. It is anticipated that other development dictated by higher energy levels, would only compound the existing problem.

### (3) CE Catapult

The description which follows is based on the U. S. Navy's CE catapult which is a land based, low acceleration, extended stroke aircraft launch system. This catapult consists of four separate systems which are: the power plant, tow cable, control, and shuttle/shuttle arrester system. See Figure 40.

The power plant prime mover consists of two turbo jet engines which exhaust into an air connected power turbine which has an integral shaft. See Figures 41 and 42. The shaft is connected through a gearbox to a capstan which contains several loops of wire rope. A hydraulically actuated brake is located between the gearbox and the capstan to stop the tow cable and other moving parts at the end of a launch.

The tow cable system as shown in Figure 43 consists of an endless loop of wire rope which runs on a predetermined path on the runway. The tow cable is turned by sheave assemblies located on both ends of the runway. The cable is driven by friction through the capstan. Part of the tow cable comes off the capstan and around a set of reeved sheaves in a hydraulic/air actuated compensator which maintains the proper tension in the cable to cause the capstan and cable system to function as a friction drive.

The control system consists of a main console and deck edge controls. The main console provides all the operating and monitoring devices required for the control and safe operation of the catapult. The deck edge controls provide safety interlock devices and the communications system between the deck edge and the console operator.

The shuttle, Figure 44, is a low profile, wheeled vehicle on which the nosewheel of the aircraft is placed and which houses the cable clamp by which the shuttle is attached to the tow cable thus supplying the tow force to the aircraft or other vehicle to be launched. The aircraft is attached to the shuttle by means of a bridle which connects hooks on the shuttle to the tow hooks on the aircraft. At the end of the acceleration run, catapult power is decreased

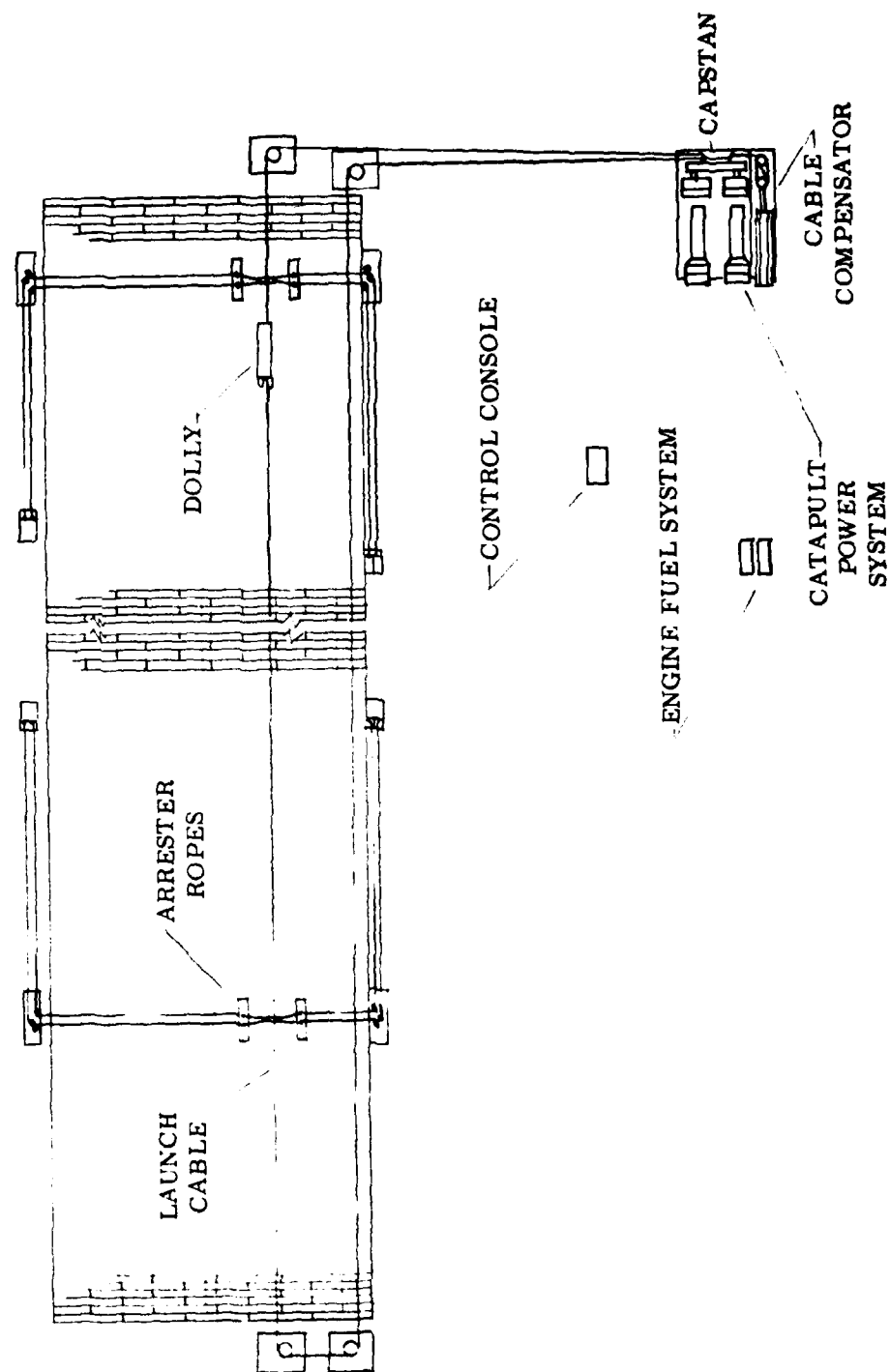


Figure 40. General Arrangement CE Catapult

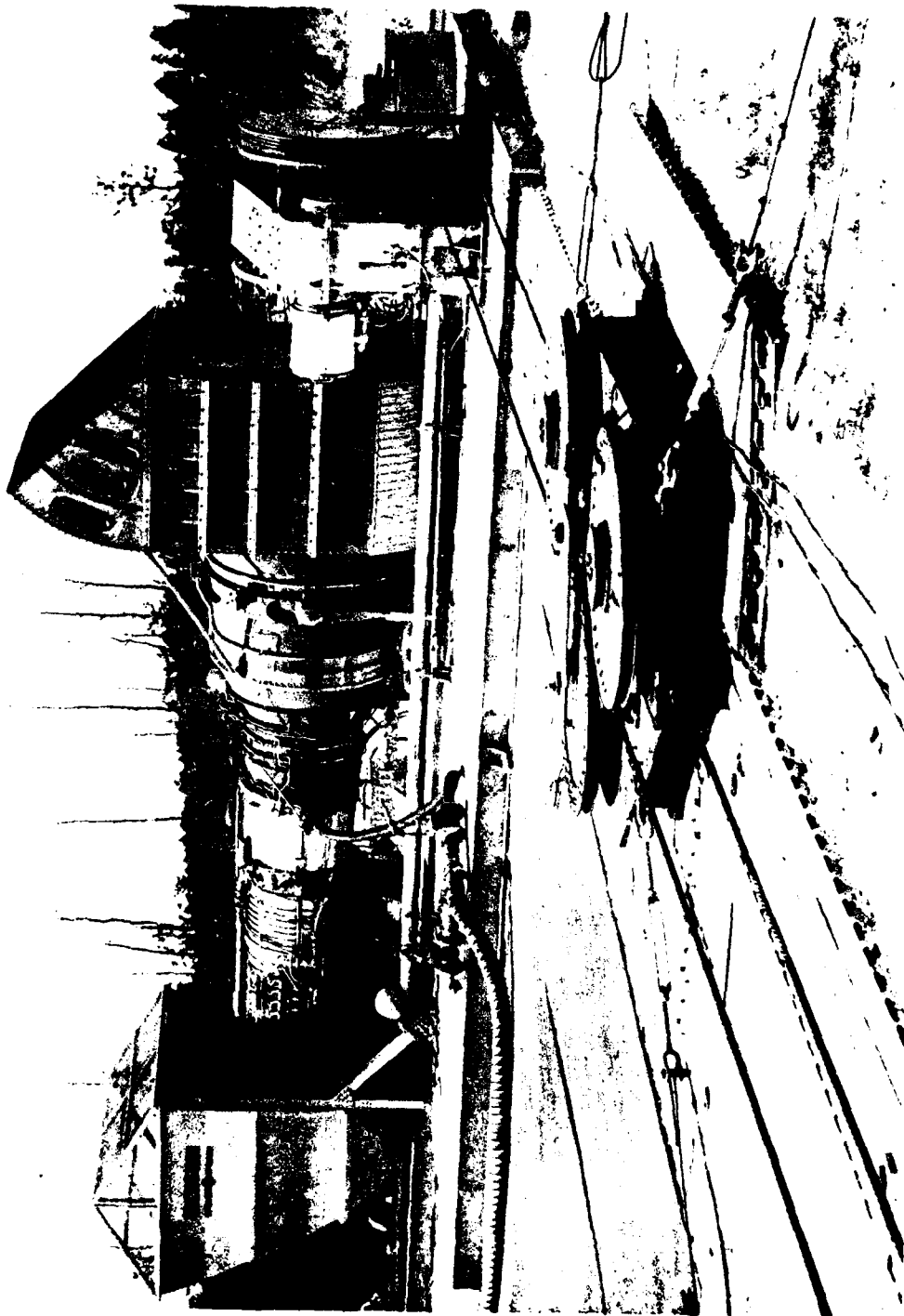


Figure 41. CE Catapult Power Plant Installation



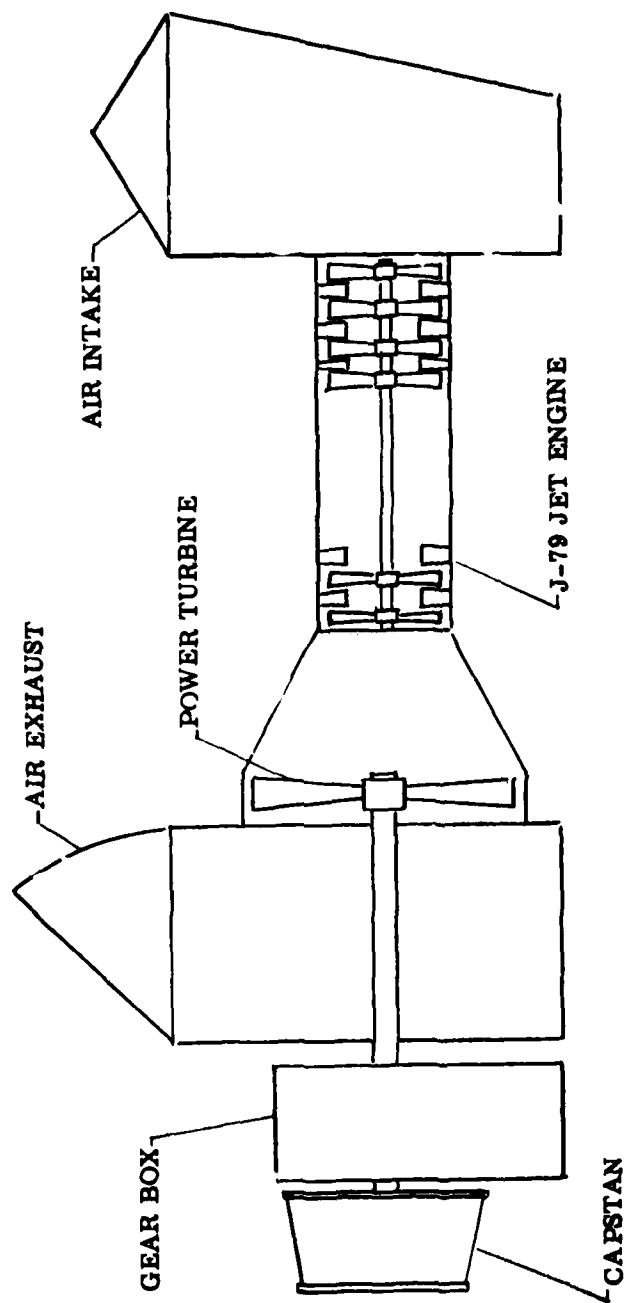


Figure 42. CE Catapult Power System

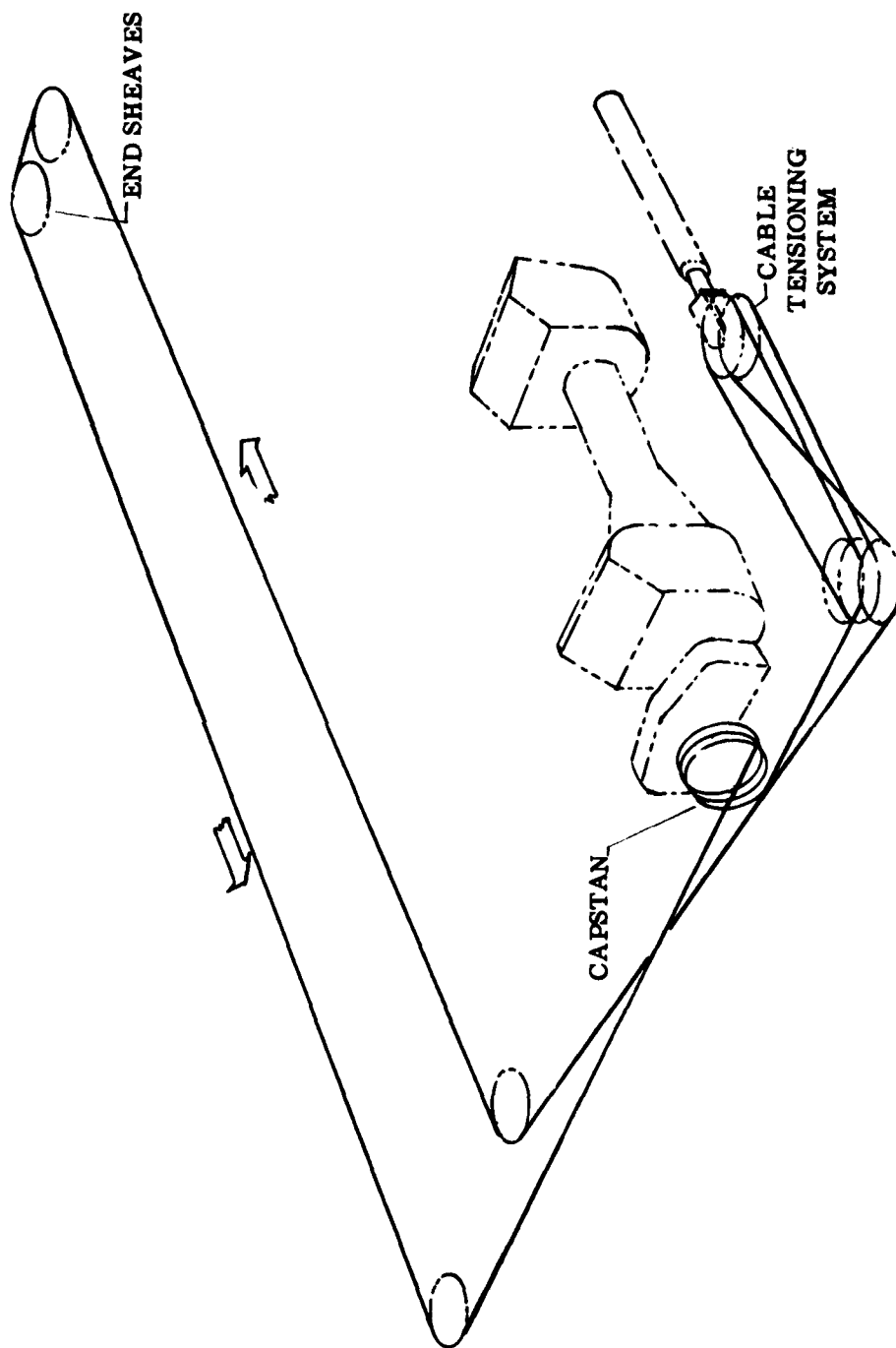


Figure 43. CE Catapult Cable System Schematic



Figure 44. CE Catapult Shuttle

and the aircraft overtakes the shuttle, rotates, and becomes airborne. The shuttle, still clamped to the tow cable, continues moving in the direction of the aircraft until the front of the shuttle impacts a pair of nylon ropes stretched across the runway. The ropes exert enough force on the clamp to disconnect it from the tow cable and then continue to stretch, decelerating the shuttle to zero speed. The shuttle's kinetic energy which has been partially stored in the nylon ropes is then used to return the shuttle to the starting or battery position. The return operation interconnection between the shuttle and the tow cable is analogous to a bead on a string. At the battery end of the launch stroke there is a similar shuttle arrester system which stops and then holds the shuttle to prevent movement toward the terminal end again. The catapult is then ready to launch the next aircraft.

#### c. Jet Car

The most common means of propelling a deadload vehicle in use at the present time is a multi-turbojet engine car. The jet car consists of a body/chassis assembly supported by four wheels and containing multiple turbojet aircraft engines for propulsion. See Figures 45 and 46. Also included in the vehicle are the necessary subsystems including fuel tanks, throttle controls, injection water tanks and fire control systems. Directional control is maintained by a guide attached to the underside of the vehicle engaging a guide rail in or above the runway surface.

Structural extensions to the chassis provide a means for pushing the load to be accelerated. At a predetermined position along the acceleration stroke, the jet engines are cut off and a series of brake assemblies which are towed behind the jet car engage a vertically expanded section of the guide rail to provide controlled braking. The deadload vehicle separates from the jet car and continues at the desired velocity into the energy absorber. The jet car could also be stopped by means of an arresting gear system, thereby eliminating the drag brakes.



Figure 45, Four Engine Jet Car

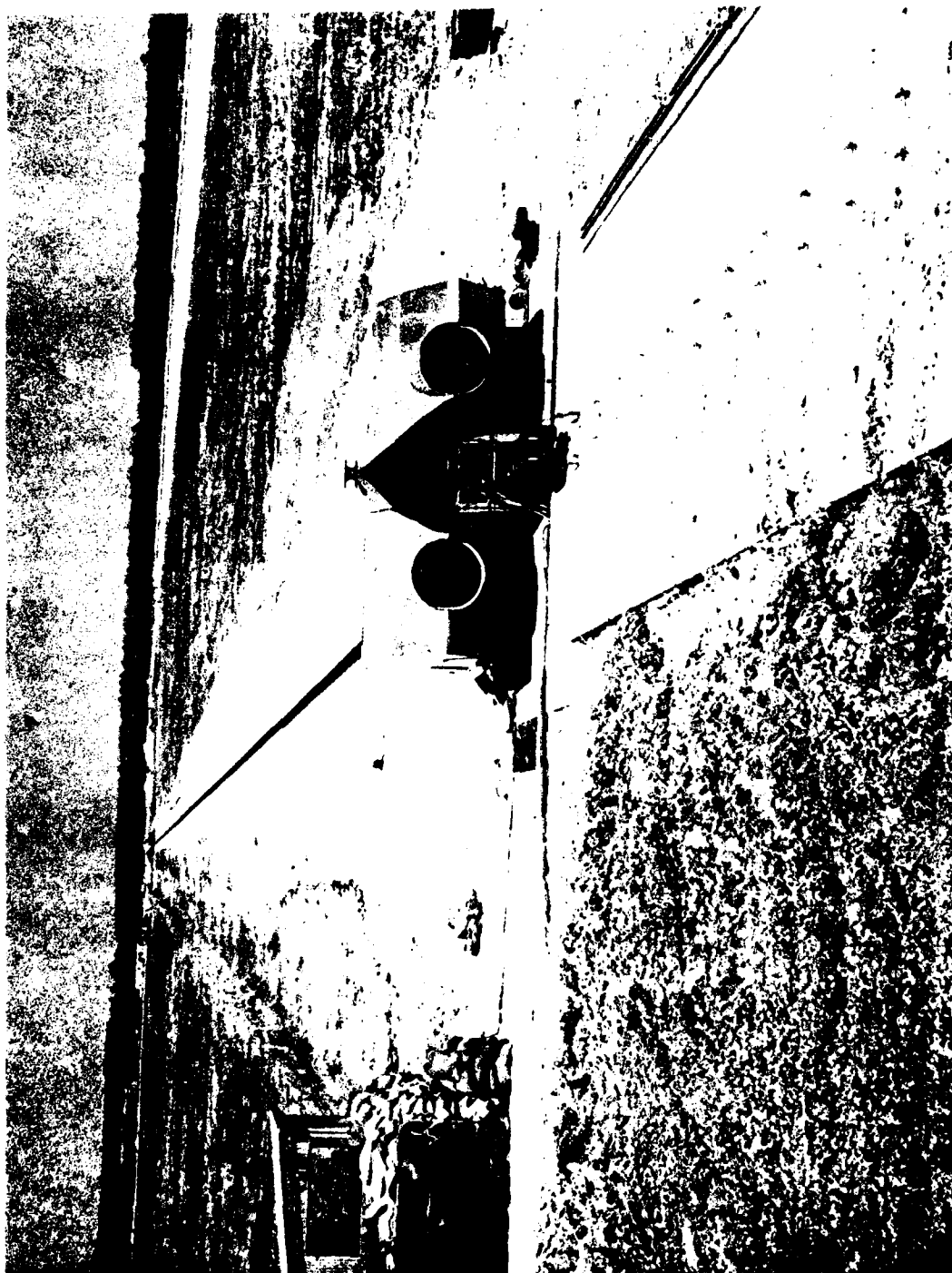


Figure 46. Two Engine Jet Car

A variation of this system which has been tested and utilized successfully is to install an arresting hook on the jet car and, after engine cut-off, arrest the jet car as part of the deadload with the energy absorber being tested. In this configuration a hard connection between the deadload and the jet car is required.

#### 4. COMPARISON OF OPERATIONAL SYSTEMS

The five operational propulsion systems were next compared or evaluated with the aid of a system which makes use of "Emphasis Curves". The complete reference for this system is included in this report in Appendix III.

A list of pertinent rating parameters was first compiled to provide a common basis for the evaluation of the operational systems. This list, displayed alphabetically, appears below and is followed by a detailed definition of each parameter.

##### a. Operational Launching Systems Rating Parameters

- (1) Cost of facilities
- (2) Cost of operations
- (3) Damage Potential
- (4) Development Required
- (5) Ease of Maintenance
- (6) Flexibility
- (7) Number of Operations Personnel
- (8) Reliability
- (9) Safety
- (10) Type of Operations Personnel

##### b. Definitions of Rating Parameters

Definitions are established as follows to be used in the evaluation of each operational launching system.

##### (1) Cost of Facilities

Criteria: Initial cost required to procure and install one launch system at the AFETC as well as any facilities required for the support of same.

(2) Cost of Operations

Criteria: Cost of manhours, consumables and amortization of equipment over the next decade.

(3) Damage Potential

Criteria: Potential cost to replace and/or repair the system and its auxiliary components plus the cost of downtime as a result of damage to the launch system.

(4) Development Required

Criteria: Cost to design and develop system and required subsystems to upgrade the present equipment to that design or energy level required for the AFFTC to perform their testing and evaluation mission during the period 1970 through 1980.

(5) Ease of Maintenance

Criteria: Relative effort required to perform routine pre and post operation servicing, minor and major repairs.

(6) Flexibility

Criteria: Ability to vary the weight and speed of the test vehicle or vehicles.

(7) Number of Operations Personnel

Criteria: Total number of personnel required to operate and maintain the test site on an (as far as practical) independent basis.

(8) Reliability

Criteria: Probability of a successful test event.

(9) Safety

Criteria: Effect of a propulsion system failure.

- (a) Can test vehicle disengage?
- (b) Potential danger to personnel
- (c) Potential danger to equipment



(10) Type of Operations Personnel

Criteria: Degree of training required for equipment operators.

c. Evaluation of the Operational Propulsion Systems

Evaluation of the five operational propulsion systems in terms of the ten rating parameters to determine the optimum system in the group, as well as the relative merits of each of the others, can be accomplished most effectively by a procedure that systematically compares each propulsion system to every other system for each of the rating parameters. A method to accomplish this is described in Appendix III and referred to as the Emphasis Curve. The procedure employed in using this method brings the judgment of the reviewer to bear on only one decision at a time, i.e., between only two concepts at a time. The mechanics of the process result in a disciplined decision making procedure that accounts for every individual judgment that must be made. In this process, no substitution is made for the judgment of the evaluator(s). Each decision is thus based upon the evaluator's knowledge of the candidate propulsion systems and his deliberate consideration of the factors involved. Since in using this system, a judgment factor must be used, two expert persons were asked to perform the analysis in order to minimize the possibility of bias. The end results of both analyses were in basic agreement.

(1) The first step in the evaluation was to analyze the ten rating parameters to determine their importance relative to each other as factors upon which to judge each of the candidate propulsion systems. In this step the parameters were listed and individual judgments made, considering which of the two parameters being evaluated was the most important based on the projected workload of the AFFTC. When the results of the analysis were collected, a numerical scoring or ranking was obtained that established the order of importance and at the same time determined their quantitative ranking within the order. The order of importance of the rating parameters and the relative importance factors as established by the analyzer, therefore, are as follows:

Relative	Parameter	Relative Importance Factor
	(a) Safety	10
	(b) Reliability	9
	(c) Cost of Facilities	8
	(d) Degree of Development Required	7
	(e) Damage to Equipment due to Malfunctions	6
	(f) Cost of Operations	5
	(g) Ease of Maintenance	4
	(h) Flexibility	3
	(i) Type of Operations Personnel (Skilled or unskilled)	2
	(j) Number of Operations Personnel	1

(2) Next these parameters were broken down into an arbitrary scale and given numerical ratings as follows:

	<u>Rating</u>
(a) Safety	
(1) Maximum	9-10
(2) Moderate to maximum	7-8
(3) Moderate	5-6
(4) Minimum to moderate	3-4
(5) Minimum	1-2
(b) Reliability	
(1) High	9-10
(2) Medium to high	7-8
(3) Medium	5-6
(4) Low to medium	3-4
(5) Low	1-2
(c) Cost of Facilities	
(1) Low	9-10
(2) Moderate to low	7-8
(3) Moderate	5-6
(4) High to moderate	3-4
(5) High	1-2
(d) Degree of Development Required	
(1) None	9-10
(2) Some	4-8
(3) Extensive	1-3
(e) Damage to Equipment Due to Malfunction	
(1) Low	9-10
(2) Moderate	4-8
(3) Catastrophic	1-3
(f) Cost of Operations	
(1) Low	9-10
(2) Moderate to low	7-8
(3) Moderate	5-6
(4) High to moderate	3-4
(5) High	1-2
(g) Ease of Maintenance	
(1) Easy	9-10
(2) Moderate to easy	7-8
(3) Moderate	5-6
(4) Difficult to moderate	3-4
(5) Difficult	1-2

- (h) Flexibility with Respect to Varying the Weight and Speed of Vehicle
  - (1) High 9-10
  - (2) Moderate 4-8
  - (3) Low 1-3
- (i) Type of Operating Personnel
  - (1) Unskilled 9-10
  - (2) Semi-skilled 4-8
  - (3) Skilled 1-3
- (j) Number of Operating Personnel
  - (1) Small 9-10
  - (2) Moderate 4-8
  - (3) Large 1-3

(3) The operational systems, rocket car, steam catapult, flywheel catapult, CE catapult and jet car were then rated against each other for each of the parameters in turn. Examples of the reasoning used in this rating process are shown below:

(a) Safety

The steam catapult was assigned a rating of 9 on a scale of 10 which when multiplied by the importance or scale factor of 10 produces a 90 for this system when evaluated for this parameter. This catapult is judged to be this safe by virtue of an estimated 500,000 launches over the last 25 year period of Naval aviation history. This system is undoubtedly the safest and most reliable method of assisting aircraft in the take-off operation known today. A 10 rating was not assigned to this or the other systems because of a small number of accidents attributable to these propulsion systems.

The jet car also rated a 9 because of the two operational jet car facilities that have been in use for an aggregate total of some 26 years. During this time a total of some 20,000 test events have taken place with no known fatalities but with some accidents.

Rocket cars or more properly, sleds, have been operational for some time and have been important test tools in the space program and in the field of biomedicine. They are inherently as safe as the propulsion elements which are handled carefully with many unique safety precautions required. Because of the extra care handling required this system was rated as 6 or 60 when multiplied by the relative importance factor.

The one operational flywheel catapult is located at the French Aviation Test Center in Istres, France. It is this contractor's understanding that this catapult has failed catastrophically on two occasions and although the failure frequency is unknown the confidence level for safety of operation is comparatively low. Therefore, this system was given a rating of 5 or 50.

Similarly, the CE catapult was rated as a 5 or 50 when safety is considered because of the past history of cable failures on this equipment during its development era.

(b) Reliability

As defined usually, reliability can be related to the probability of accomplishing something, such as a test event, successfully. Reliability is generally proportional to the amount of time that a system has been operational and/or the amount of money spent to make it operational. Reliability is generally inversely proportional to the degree of complexity or the total number of components which must perform successfully in a programmed sequence.

Thus the reliability of a jet car is determined by the probability of starting and running to power four, six, or perhaps eight turbojet engines. This event takes place many times every day in world wide military and commercial aircraft operations. This system is considered to be 98 percent reliable after the start up has been accomplished. The jet car system, therefore, was rated a 10 or 90 when multiplied by the relative importance factor of 9.\*

The steam catapult, a vital part of the Navy's air arm, is generally known to be a reliable system. It is not as reliable as the jet car system, however, due solely to the comparatively large number of components, all of which must work in sequence in order to have a successful launch. Based on this criteria, this system was given a 9 rating.

The rocket car also rated a 9 based on the utilization of rockets which would have unused shelf life. In this system the reliability is keyed to the ignition process. Thereafter the burning of the fuel is practically assured. In comparison, the use of obsolescent rockets with expired shelf life would present a potential major hazard or generate the requirement to x-ray the propellant grain before use. Use of obsolescent rockets would reduce the reliability rating to 4 or below.

The CE catapult was given a rating of 6. This system has a fairly complex but basically reliable control system as well as the requirement for the successive operation of several key components. During the past several years of development testing and service evaluation there have not been any launches in which the aircraft has failed to become airborne or achieve some lesser programmed velocity.

The flywheel catapult is currently known to have some as yet to be resolved development problems. According to information received by this contractor the flywheel has failed on two occasions. This flywheel was designed by a knowledgeable sub-contractor and the ultimate reason for this problem must be speculated. A rating of 4 was assigned to this system.

\*Note: From hereon, the initial rating number will be indicated in the text; the multiplication by the relative importance factor will be shown only on Table II.

TABLE II  
OPERATIONAL PROPULSION SYSTEMS EVALUATION

	Safety	Reliability	Cost of Facilities	Development Required	Damage Potential	Cost of Operations	Ease of Maintenance	Flexibility	Type of Operations Personnel	Number of Operations Personnel	TOTAL
Importance Factor	x10	x9	x8	x7	x6	x5	x4	x3	x2	x1	
Jet Car	90	90	56	56	60	40	40	27	10	6	475
Rocket Car	60	81	48	70	60	5	40	12	2	10	387
C.E. Cat	50	54	16	42	24	25	20	24	8	6	269
Flywheel Cat	50	36	16	42	24	25	20	24	8	6	251
Steam Cat	90	81	8	14	30	20	12	30	14	6	305

### (c) Cost of Facilities

The logical way to rate the five propulsion systems based on this parameter is to use one as a base and compare the other four to it.

A jet car facility proposed for the AFFTC, completely installed and ready for test is estimated to cost between two and two and one-half million dollars. Compared to the estimated cost of the other candidate systems, this is considered to be a low to moderate cost for such a facility. Therefore, this system was assigned a rating of 7.

A rocket car facility would be the next least expensive facility. This system would not require the turbojet engines needed for the jet cars, proposed to be furnished as GFE, but would require storage and conditioning buildings that do not exist at the present time. Thus, this facility would require more funds and is assigned a 6 rating as a moderate cost system.

In consultation with the manufacturer of a leading jet engine company, it was generally stated that a power plant that is 10 to 12 times the capacity of the present CE, i.e. in the order of 350,000 to 420,000 hp, would be very expensive. Power plants of this size, at this time, are not envisioned as practical. A 50,000 hp prototype has been built, with moderately higher capacity power plants envisioned. This contractor estimates that a CE type catapult having this power requirement would cost four to five million dollars by the time the one system was installed. The facility cost is, therefore, high and consequently a 2 rating was assigned to this system for this parameter.

The flywheel catapult was also assigned a rating of 2. One advantage of this catapult as compared to the CE is that the power plant can be appreciably smaller. On the other hand, it would require a flywheel that probably would be larger than any manufactured to date, as well as high capacity clutches which also are not known to exist. In other words, the facility cost is considered to be high for this equipment due mainly to the required development of key components other than the power plant.

The steam catapult is the only one of the candidate propulsion systems that requires an on-site facility to generate the basic means of propulsion. This steam generating plant by virtue of its rather unique components would require an investment of 500,000 to 750,000 dollars. It is estimated that a 3000 foot long steam catapult would cost at least 5,000,000 dollars to develop. This system was, therefore, given a 1 rating for this parameter.

### (d) Development Required

In the case of the J79 jet car, development is not required inasmuch as NATF has manufactured such a car to an All American Engineering Company design. This car is currently being operated at that facility. This state-of-the-art need not be expanded to encompass a jet car powered by TF-39 engines. No jet car of this power has been built or designed, but the physical

size alone is not envisioned as a major problem. Based primarily on the requirement to design a jet car based on the nominal nine foot diameter TF-39 engines, this system was rated as 8.

The rocket car system was given a rating of 10 based on the fact that rockets having several million tons of thrust are reliably taking men to the moon and back. The proposed application of this system for the AFFTC propulsion requirement would resolve itself to the design of a suitable car or wheeled frame on which to mount the rockets. However, rocket motor combinations to provide the exact impulse requirements to deliver varied combinations of weight and speed are probably not readily obtainable.

In order for a CE catapult system to launch deadloads of the magnitude required for the AFFTC during the next decade, the power requirement would have to increase by a magnitude of 10 to 12 times based on the same nominal power stroke. The increase would be five or six-fold if the power stroke were doubled. Additionally, the increased power requirement would also generate a requirement for a larger launch cable, cable compensator, and the shuttle and shuttle arrester. The most expensive development effort would be that devoted to the power plant. Based on the rather extensive development effort required, this system was given a 6 rating for this parameter.

The flywheel catapult system was given the same rating for this parameter as the CE catapult. Although the power requirement would be smaller, other key components such as the flywheel, clutches, and brake have not been developed in this capacity as of this date. The tape required for a catapult of this capacity would exceed the present tape manufacturer's capability; however, if the design was modified for cable, the tension member is probably available.

It is anticipated that the development of a steam catapult to meet the projected testing power requirements for the AFFTC and patterned after the Navy's C-13 catapult would entail an expensive and time consuming development program. The present high reliability enjoyed by the C-13 steam catapults was achieved through years of development and improvement programs which were necessarily expensive. Although the reliability of the large steam catapult envisioned for the AFFTC would not have to be as high as that required for the Navy's operational systems, the development of a nominal 3000 foot long steam catapult would by its very nature be prohibitively expensive. For this reason, this system was given a 2 rating for this parameter.

#### (e) Damage Potential

Jet cars as they are currently utilized are made as a rugged structural frame on which aircraft wheel assemblies are mounted and usually, surplus aircraft turbojet engines. The engines are the components most susceptible to damage but the car frame usually does not incur irreparable damage when and if it overruns both the test and overrun arresters, provided it stays upright.

A jet car facility would usually have a reasonable supply of spare engines and/or engine components which could be used to refurbish the car in case of an accident. The complete assembly can normally be refurbished or otherwise brought back into an operational status without much direct expense or facility downtime. Based on these considerations, this system was given a 10 rating for this parameter.

The above also applies to a rocket car system of propulsion except for the fact that the rocket cases would normally be expendable if the rockets used were surplus or non-surplus flight weight versions, i.e., this type of rocket case would require replacement whether the car was in an accident or not. The car and propulsion system would be comparatively easy to repair and, therefore, was assigned the same rating of 10 as the jet car.

The basic design of the steam catapult is predicated on its being an essentially permanent installation or an integral part of an aircraft carrier. With this design philosophy the accent is on reliability and not necessarily ease of access or replacement that is the case with expeditionary equipment. Catapult malfunctions aboard carriers are, on occasion, major. The subsequent cost in direct repair and downtime is also a major item. Based on the high cost to repair this system after an accident, due to a malfunction, this system was rated as 5.

The CE catapult system is usually pre-operationally checked by launching the cable and then the shuttle. Both are checks of the control system; the latter launch is also a check on the status of the shuttle and shuttle arrester. The system is then ready for deadload or aircraft operations. Minor malfunctions with this system in the past are usually traceable to the control system. Major malfunctions center around the failure of the shuttle arrester to stop and then return the shuttle which in turn usually causes the launch cable to be cut by the shuttle as it goes through the terminal end sheave. To date this malfunction has not harmed aircraft, deadload, or personnel but does result usually in the requirement to replace or repair most of the hardware on the runway. Based on this analysis of damage potential, this system was assigned a 4 rating for this parameter.

This contractor does not have any direct experience generated by failure of the flywheel catapult. From general knowledge of associated equipment as well as design studies it is possible to assess the damage potential of this type of equipment. It is understood that the flywheel has failed catastrophically on two occasions. This failure is the most critical and would require the replacement of this long lead and expensive component. This system was rated a 4 for this parameter.

#### (f) Cost of Operations

The operation of a jet car facility is in part based on a supply of surplus jet engines and aircraft wheels and tires as GFE which is procured at little or no cost. Thereafter the cost of operations is almost negligible as evidenced by this contractor's recent rental of our test site to a customer for



\$500.00 per test day and approximately \$140.00 per test for consumables if the schedule would permit more than one test in a given day. Based on this, the system was assigned an 8 rating for this parameter.

The rocket car system on the other hand represents the other end of the scale. As shown in previous discussions of this system, the basic rockets are expensive if purchased new. Consideration has been and will be given to the use of surplus rockets which, of course, will be procured at substantial savings in cost but would still entail the use of a comparatively expensive source of propulsive power. This system was assigned the minimum rating of 1 for this parameter.

Both the CE and flywheel catapults would be more expensive to operate than a jet car due to the attrition of on-deck hardware and components which do not exist on a jet car system. Examples are the launch cable or tape, sheaves, and shuttle parts. These systems were, therefore, assigned a 5 rating. The operating cost for the generation of steam for a 3000 foot long steam catapult would be approximately \$1,750,000 based on multiplying a known yearly cost at NATF for supplying steam to one catapult there and the ten times growth factor required by the AFFTC. This estimated cost is derived as follows:

- (1) Present length of C-13 Steam Catapult: 300 feet.
- (2) Estimated length of steam catapult for the AFFTC:  
3000 feet.
- (3) NATF yearly cost for intermittent operation of two steam catapults: \$350,000 or \$175,000 for each.
- (4) Estimated yearly cost for one 3000 foot long steam catapult:  $10 \times \$175,000 = \$1,750,000$ .

The steam catapult was rated as 4 for this parameter as being the most expensive to operate.

(g) Ease of Maintenance

Of the five candidate propulsion systems maintenance on a jet car is accomplished more readily. The engines are usually accessible after sheet metal protective shrouds are removed; maintenance can be accomplished by civilian mechanics or by United States Air Force enlisted personnel that are normally available at a test facility. This system was, therefore, given a 10 for this parameter.

Since there would be virtually no maintenance on a rocket car this system also is rated as 10.

On the CE catapult the engines do not present any greater maintenance problem than they do on the jet car. The shuttle maintenance is not

difficult but has usually been accomplished by a mechanic who enjoys a challenge. Maintenance of the control system would require an electrical or electronic technician. For these reasons this system was rated as a 5.

The flywheel catapult should be as easy or easier to maintain than the CE since it has a less complicated shuttle and does not require a cable compensator or component analagous to it. This system was thus given a 5 rating for this parameter.

The steam catapult was given a 3 rating for this parameter; it is more difficult to maintain than any of the other systems.

#### (h) Flexibility

The jet car system has, inherently, the most flexibility for varying the weight and speed of the test vehicles. Allowance must be made for changing the deadloads at convenient steps throughout the test program based on the weight ranges to be tested. Percent rpm and therefore power is the only change required for different end speed and/or weight requirements. This system accordingly was given a 9 rating.

Launch weight and speed requirements are varied on the CE catapult by varying the maximum rpm at which the engines will run during the power stroke. This is an easy adjustment made on the control console. In addition to this the effective power stroke may be decreased from the maximum available; again by an adjustment on the console. This system was rated as an 8 for this parameter.

The power plant for the flywheel catapult runs at maximum rpm throughout the launch stroke. Flexibility would be accomplished by effectively varying the power stroke by disengaging the clutch as required. This system is considered to be as flexible as the CE and, therefore, was given the same rating.

Since the exact requirements of impulse to propel a given test vehicle weight to a certain desired end speed would be difficult to obtain, the rocket car principle of propulsion is inherently not flexible. Based on this, the system was assigned a 4 rating for this parameter.

The steam catapult was rated as a 10 for this parameter. In this system variation would be accomplished by varying the steam pressure only as is now done on the Navy's operational catapults.

#### (i) Type of Operations Personnel

Mechanics trained in the operation and maintenance of jet engines would obviously be required for the jet car, CE, and flywheel catapult systems. Personnel having experience in the care, handling and operation of rockets would be required for a rocket car system. Personnel trained in the

operation and maintenance of the steam catapult would be required for this unique type of equipment; these people do not currently exist within the Air Force. The five candidate systems were assigned ratings as follows for this parameter:

- Jet Car - 5
- Rocket Car - 1
- Steam Catapult - 7
- CE Catapult - 2
- Flywheel Catapult - 2

(j) Number of Operations Personnel

A rocket car system would require the minimum number of people for operations. The other four systems would require approximately the same number for operations. These systems were rated as follows:

- Rocket Car - 10
- All Others - 6

(4) After evaluation of the five candidate propulsion systems based on the ten parameters, the results of the evaluation were tabulated, as shown in Table II. This table shows the jet car propulsion system, with the highest score, to be the most desirable system for the AFFTC.

## 5. COST COMPARISON OF ROCKET CAR AND JET CAR OPERATION

Since the preceding comparison showed that a turbojet engine and a rocket car were the prime and alternate systems of propulsion it is necessary to compare the two from the standpoint of cost of operations. For the sake of simplicity the cost comparison will be based on an arbitrary thrust requirement of 50,000 pounds acting for a period of one minute, i.e., 50,000 pounds  $\times$  60 seconds or 3,000,000 pound seconds. It is assumed that a J79-5 engine costs \$250,000.00 and that its useful life would be 1000 cycles under this method of operation. The estimated useful life is based on an established service life of J-79 engines at 2,000 cycles when used as the power plant for the CE series of catapults. The four engines are costed therefore at \$1,000,000.00 which results in an engine cost per test event of \$1,000. Fuel cost per event is estimated at \$100.00 and it has been observed that approximately the same number of people are involved in the operation of either a rocket car or jet car.

Reference is made herewith to Appendix 1, Item 8 enclosure which states that a rocket motor in the 64,000 pound thrust class and a burn time of 67.2 seconds would have a rough order unit cost of \$250,000.00. This cost when ratioed down to compare directly with the 3,000,000 pound second thrust unit is \$174,375 per test event.

## 6. PERFORMANCE OF JET CARS

### a. Accelerating Stroke

The arresting gear test facility at the AFFTC has the arresting gear installation area 6000 feet from the westerly end of the runway. Approximately 100 feet must be allowed at the terminal end for engine shutdown and arrestment of the jet car. Battery end facilities utilize an additional 100 feet. This gives a total usable acceleration stroke of 5800 feet.

### b. Loss Factor

In the past and before the advent of computers the performance of jet cars was done empirically utilizing an inefficiency or loss factor which through use was 15 to 25 percent. A 25 percent loss factor was assumed in the early part of this study so that performance data could be generated on a preliminary basis. Thereafter, it was decided to set up and run a computer program to verify the preliminary data and to conduct a parametric study at the same time.

### c. Analytical Evaluation

Accelerating a mass from rest with constant thrust has formed the foundation for analytical evaluation of jet car acceleration. The problem has been solved with friction and aerodynamic drag losses taken into account. As thrust and stroke are the primary parameters of interest in jet car design, rather than acceleration and time, the solution was formulated using energy considerations.

Basically, the following governing equation was evaluated:

$$\text{Energy Supplied} - \text{Energy Lost} = \text{Change in Kinetic Energy} \quad (1)$$

The energy supplied is the jet car thrust (the thrust is a constant and denoted by the symbol, T) acting over the stroke, S. The energy lost is the sum of friction and aerodynamic drag forces acting over the same stroke.

The friction force is given by:

$$F_f = W C_f \quad (2)$$

where:

$F_f$  = friction force, pounds

W = total weight, pounds

$C_f$  = coefficient of friction = 0.018

The linear weight dependent relation (2) and the value of  $C_f = 0.018$  were suggested by Lakehurst personnel as the value that they use for similar jet car studies. Lakehurst indicated that the value comes from experimental jet car acceleration data.

The aerodynamic force is given by:

$$F_a = \frac{1}{2} \rho V^2 C_D A \quad (3)$$

where:

$F_a$  = aerodynamic drag force, pounds

$\rho$  = sea level air density, pounds-sec.<sup>2</sup>/ft.<sup>2</sup>

V = instantaneous velocity, feet/second

$C_D A$  = product of drag coefficient and area, feet<sup>2</sup>

$C_D A$  will be referred to as the drag factor. In evaluating the drag factor, the individual contributions of the engines, engine nacelles, and frontal area were established. Drag losses arising from interactions with the ground, wheels, and unclear aerodynamic shape were disregarded. Hence,

$$C_D A = (C_D A)_E + (C_D A)_N + (C_D A)_F \quad (4)$$

As exact values for each  $C_D$  could not be determined, and to include, if possible, other disregarded aerodynamic losses, a range of  $C_D$  was established for a jet

car corresponding to a minimal, nominal, and maximum expected value of drag factor. Thus, the values of  $C_D A$  considered range from a minimal drag factor with  $(C_D)_E = 0.05$ ,  $(C_D)_N = 0.01$ ,  $(C_D)_F = 2.0$  to a maximum with each  $C_D = 2.0$ . Such conservatism should include in the drag factor the disregarded drag losses.

With the jet car initially at rest the change in kinetic energy is given by

$$KE = 1/2 M V_{T/O}^2 \quad (5)$$

where:  $M = W/g \text{ lb.-sec.}^2/\text{ft.}$

$g = \text{gravitational acceleration constant} = 32.174$

$V_{T/O} = \text{velocity at end of stroke}$

Equation (1) may be evaluated by integrating the forces given by Equations (2) and (3) over the stroke distance. This results in

$$\int_0^S (T - WC_f - 1/2 V^2 C_D A) ds = 1/2 W/g V_{T/O}^2 \quad (6)$$

The left hand side of Equation (6) presents no difficulty, except for the expression  $V^2 ds$ . This expression is evaluated by the rule of L Hopital. The range  $S$  is divided into an  $n$  increments of length  $ds$ . The velocity,  $V_j$ , is determined at  $S_j$  where  $S_j = j ds$  and  $1 \leq j \leq n$ . Hence,

$$\int V^2 ds = \sum_{j=1}^{n-1} (V_j^2 + V_n^2/2) ds.$$

Thus, as a function of stroke the take-off velocity is given by

$$V_{T/O} = \left( \frac{(T - WC_f) S - 1/2 \rho C_D A \sum_{j=1}^{n-1} V_j^2 ds}{(1/2 W/g + 1/4 \rho C_D A ds)} \right)^{1/2} \quad (7)$$

#### d. Computer Program

The solution of Equation (7) was programmed in Fortran for 1000 foot intervals over 10,000 foot stroke, with the interval 5000 stroke 6000 feet expanded in 100 foot intervals. The effect of interval length was checked by comparing the take-off velocity computed with 10 versus 100 intervals. The difference was less than 1% and did not warrant increased print-out except in the 5000-6000 foot region which is immediately beyond the end of the proposed jet car track. This program and the computerized results are not part of this report but have been delivered to the contracting activity.

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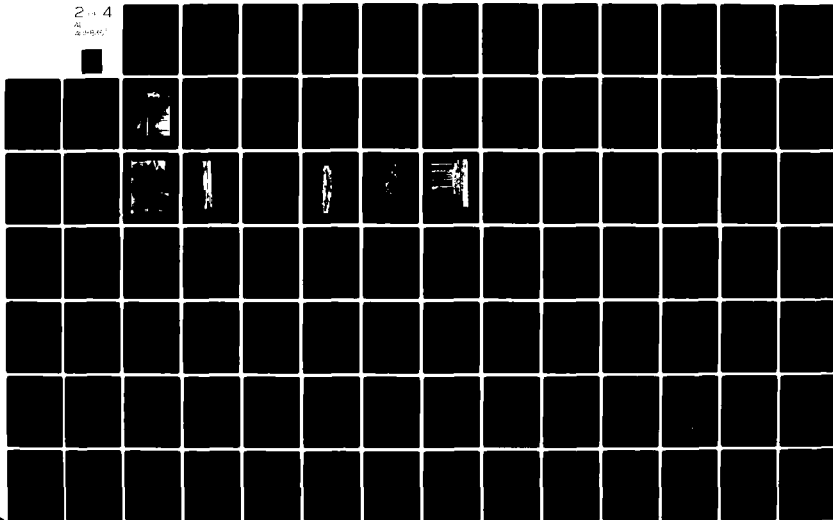
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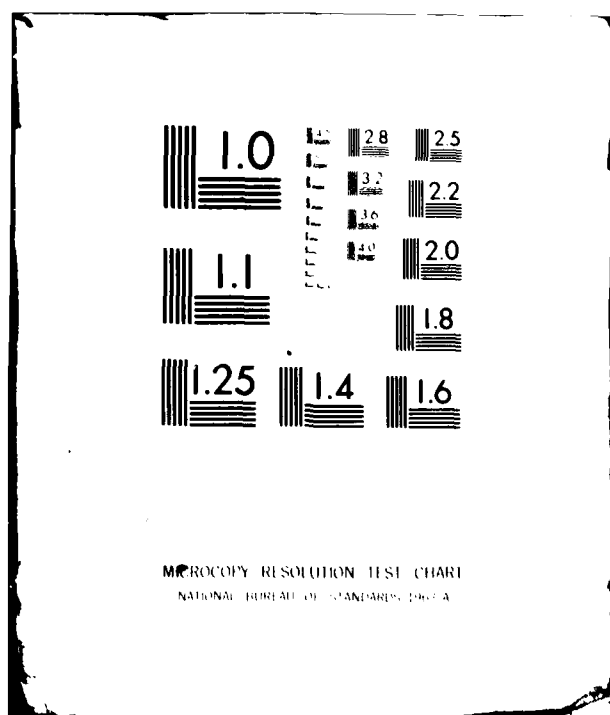
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d. Thrust Requirement Summary

The following table was extracted from the computer runs and summarizes the predicted jet car performance for an acceleration stroke of 5800 feet, 2500 foot altitude, and a 59° F day.

Table III

Thrust Requirement Summary

Aircraft	Weight Pounds	Velocity Knots	Kinetic Energy foot-lbs. $\times 10$	Jet Car Engines
F-4	60,000	280	209	J-79 (4 Engines)
FB-111	125,000	251	351	J-79 (6 Engines)
Proposed Supersonic Interceptor	150,000	235	368	J-79 (6 Engines)
B-1 Ad- vanced Manned Strategic Bomber	350,000	244	926	TF-39 (6 Engines)
C-5A	728,000	181	1062	TF-39 (6 Engines)

The performance data extracted in each case represents middle case conditions of drag. In the case of the proposed supersonic interceptor the required end speed of 235 knots is just reached within the presently available 5800 foot acceleration stroke.

Figures 47 through 50 are plots of kinetic energy versus acceleration stroke for the performance of four engine and six engine jet cars based on an altitude of 2500 feet and a temperature of 59° and 110° F. On each graph the energy levels to be simulated for five pertinent Air Force aircraft are indicated by vertical lines. The presently available acceleration stroke of 5800 feet is shown as a horizontal line. Figure 47 for example, shows that with a four engine jet car utilizing J79-5 engines that the energy simulation required for the F-4 aircraft will be reached in approximately 2100 feet of accelerating stroke and that similarly the F-111 aircraft simulation would be met in approximately 3200 feet of acceleration stroke. However, in the case of the proposed supersonic interceptor its kinetic energy simulation would require approximately

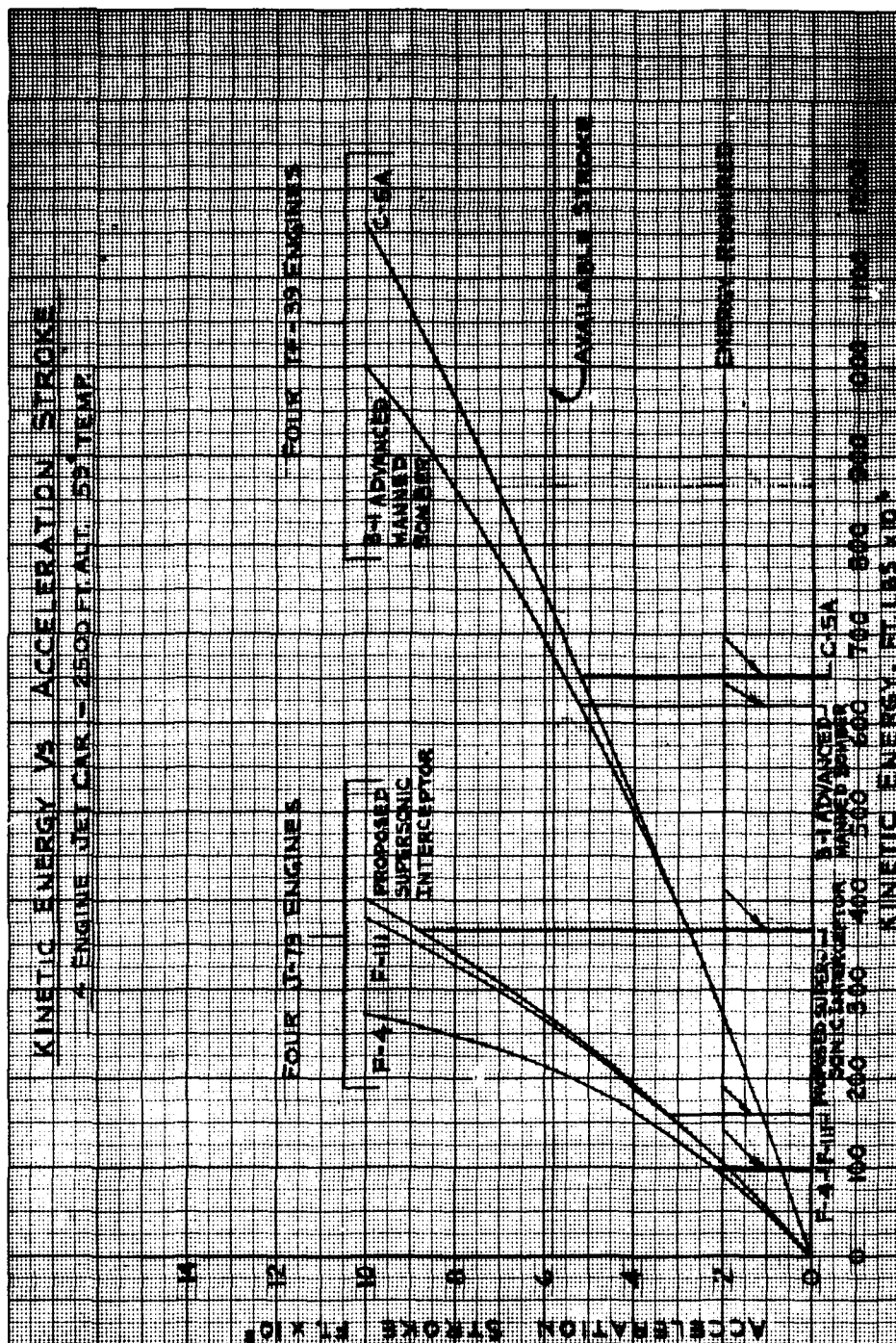


Figure 47. Kinetic Energy vs. Acceleration Stroke  
 (4 Engine Jet Car - 2500 Ft. Alt., 59° Temp.)

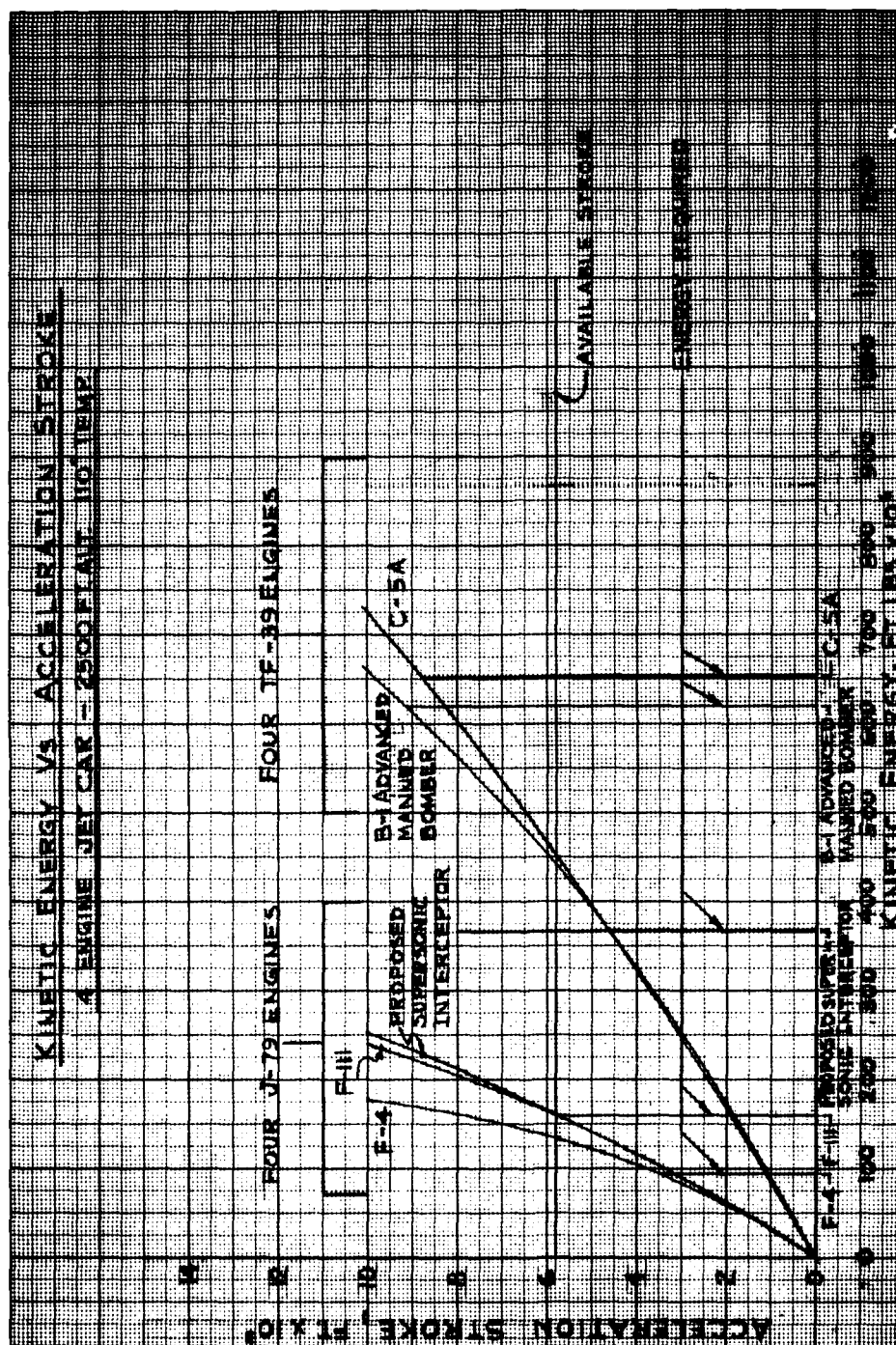
8800 feet of accelerating stroke based on J79-5 engine performance. This graph also shows that both the B-1 Advanced Manned Bomber and the C-5A Aircraft would meet their respective kinetic energy simulation within the accelerating stroke presently available.

Figure 48 is similar to Figure 47 in format but differs in that the performance shown is based on an ambient temperature of 110° F. This figure shows, for example, that to simulate the kinetic energy of a F-4 would require approximately 3500 feet of stroke. In order to simulate the F-111 all of the presently available 5800 feet of stroke would be required. In the case of the proposed supersonic interceptor the accelerating stroke required is extrapolated at over 14,000 feet. The simulation of these aircraft in this graph is as before based on the utilization of four J79-5 engines as the power source for the jet car. The right hand side of the chart shows that four TF-39 engines as the power for the jet car would require in excess of 8500 feet for the acceleration run to simulate the B-1 Advanced Manned Bomber and the C-5A Aircraft.

Figure 49 is based on using two jet cars powered by respectively six J79-5 engines and six TF-39 engines and is also based on standard day temperature conditions. The graph shows that both the F-4 and the F-111 aircrafts kinetic energy would be simulated in an accelerating stroke of 2100 feet or less and that the proposed supersonic interceptor would be simulated just within the presently available accelerating stroke. The graph further shows that by utilizing six TF-39 engines both the B-1 Advanced Manned Bomber and the C-5A Aircraft would be simulated in an acceleration stroke of less than 3500 feet.

Figure 50 is similar to Figure 49 but is based on a 110°F day. The predicted performance as shown on this graph indicates that the proposed supersonic interceptor and B-1 Advanced Manned Bomber would require acceleration strokes in excess of 5800 feet now available.

Figure 51 through Figure 54 are plots of aircraft weight versus engaging velocity based on the predicted performance of both four and six engine jet cars powered with the same jet engines for arbitrarily chosen acceleration strokes of 5800 and 8000 feet. The maximum take-off weight and the comparable take-off flying speeds are cross plotted for each of several pertinent aircraft and are indicated by small squares. These four figures in summary show the same performance that was indicated in Figure 47 through 50 but presents the information in a different manner but also includes several of the new or proposed commercial jet transports. As an example, Figure 53 which is based on utilizing six engine jet cars on a standard day shows that the energy simulation required for all the Air Force aircraft of interest would be met without the requirement for extending the runway. It also shows that in order to simulate the kinetic energy of the 747B and the SST aircraft a runway extension of about 2000 feet would be required.



**Figure 48. Kinetic Energy vs. Acceleration Stroke  
(4 Engine Jet Car - 2500 Ft. Alt., 110° Temp.)**

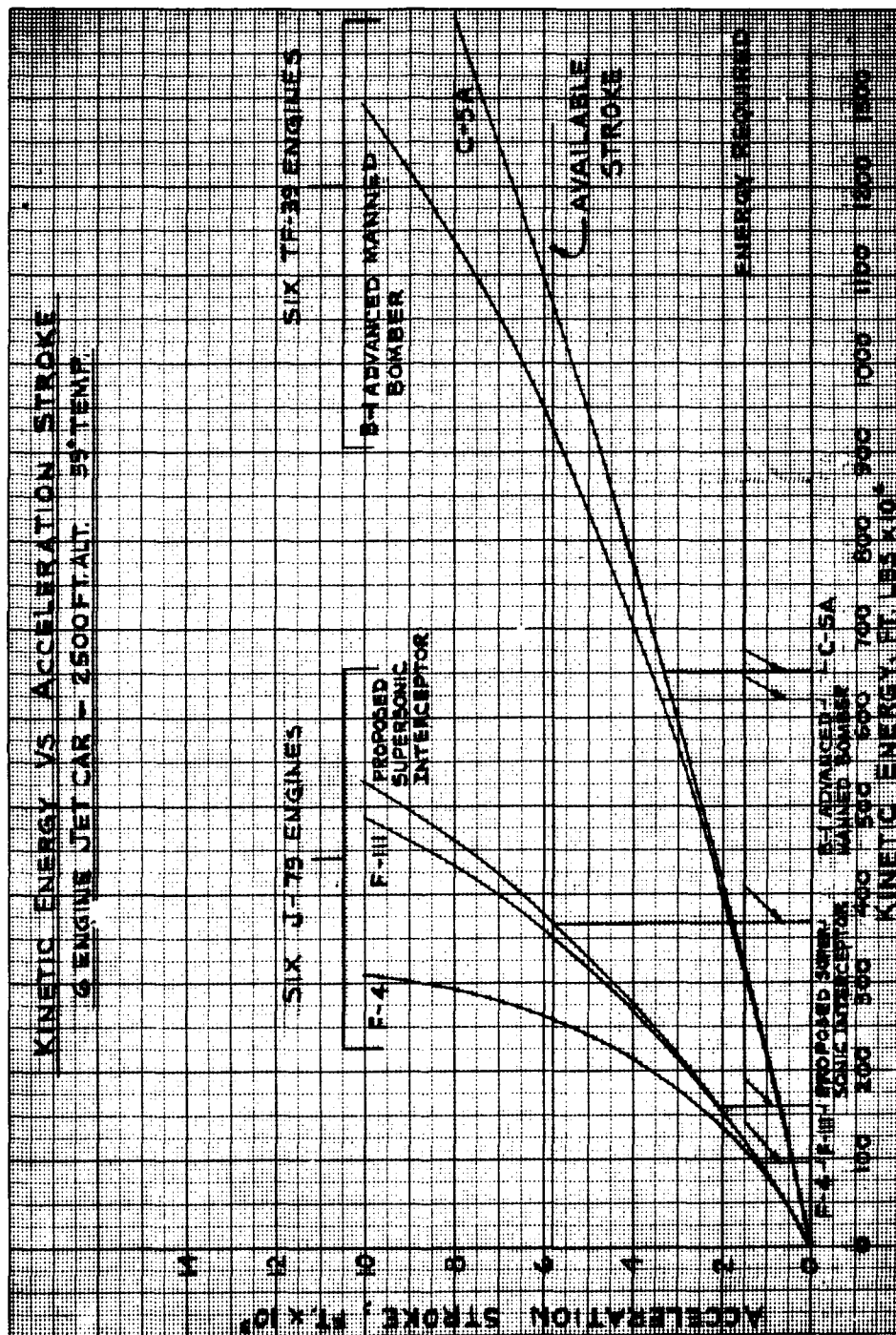


Figure 49. Kinetic Energy vs. Acceleration Stroke  
(6 Engine Jet Car - 2500 Ft. Alt., 59° Temp.)

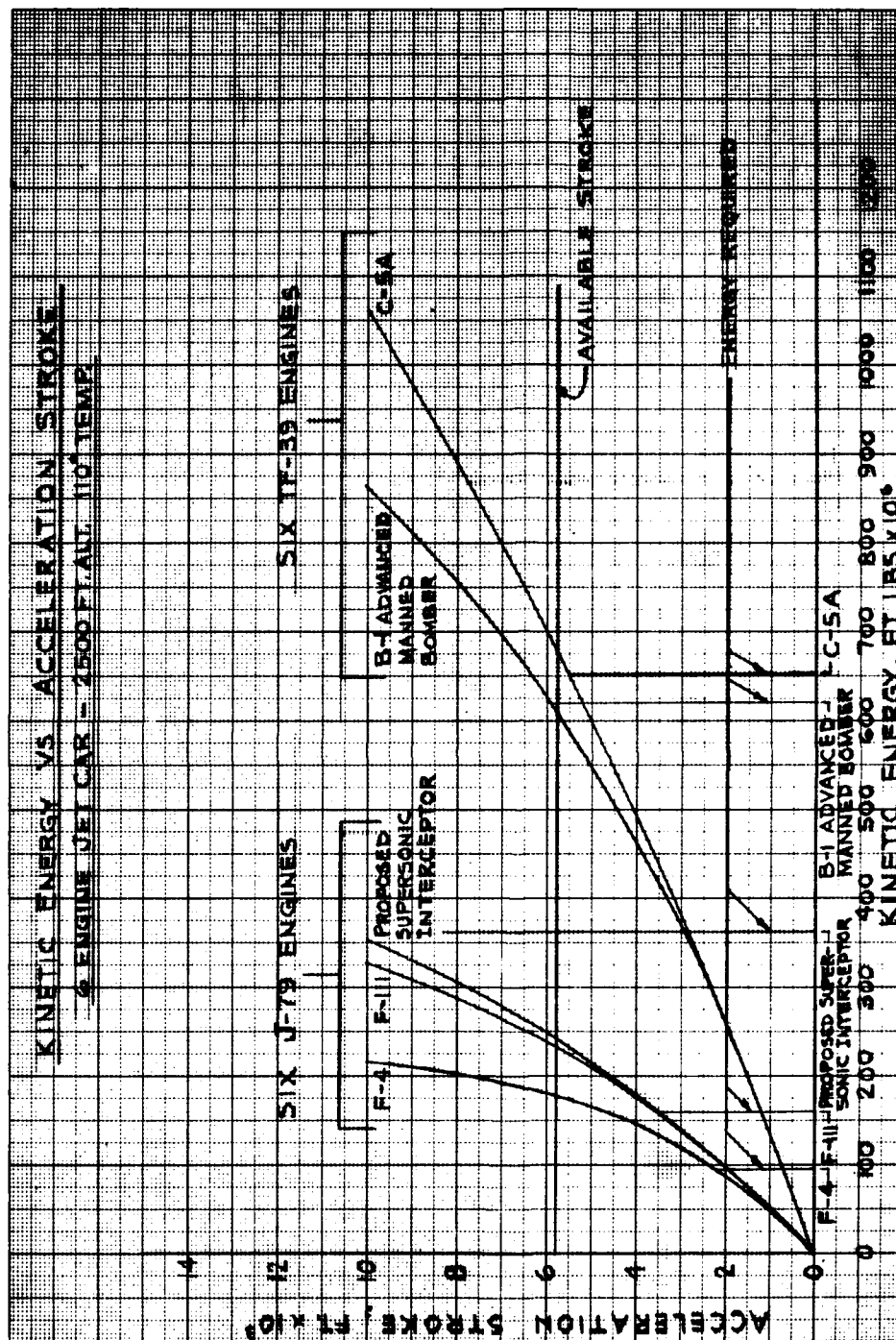


Figure 50. Kinetic Energy vs. Acceleration Stroke  
 (6 Engine Jet Car - 2500 Ft. Alt., 110° Temp.)

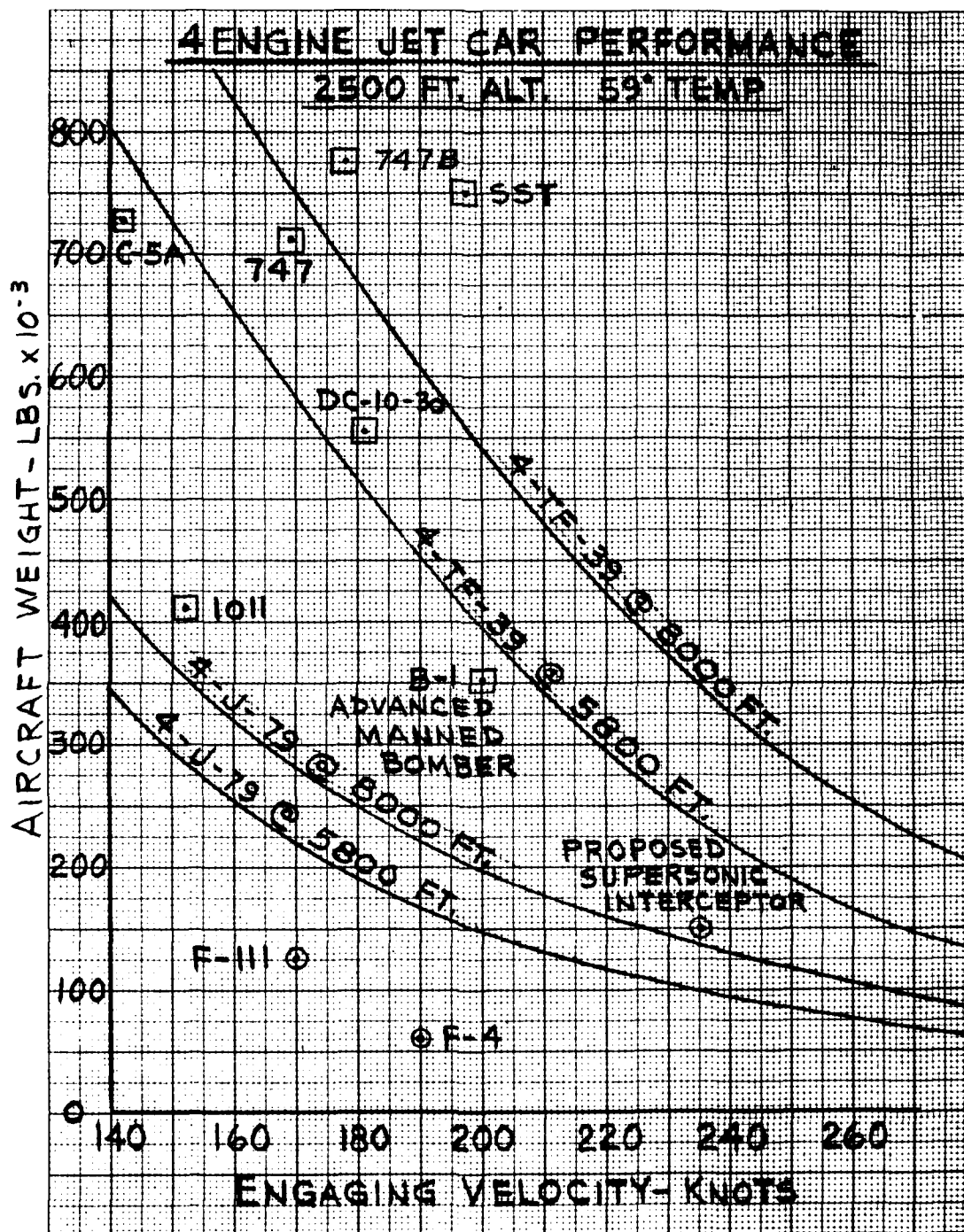


Figure 51. 4 Engine Jet Car Performance  
(2500 Ft. Alt., 59° Temp.)



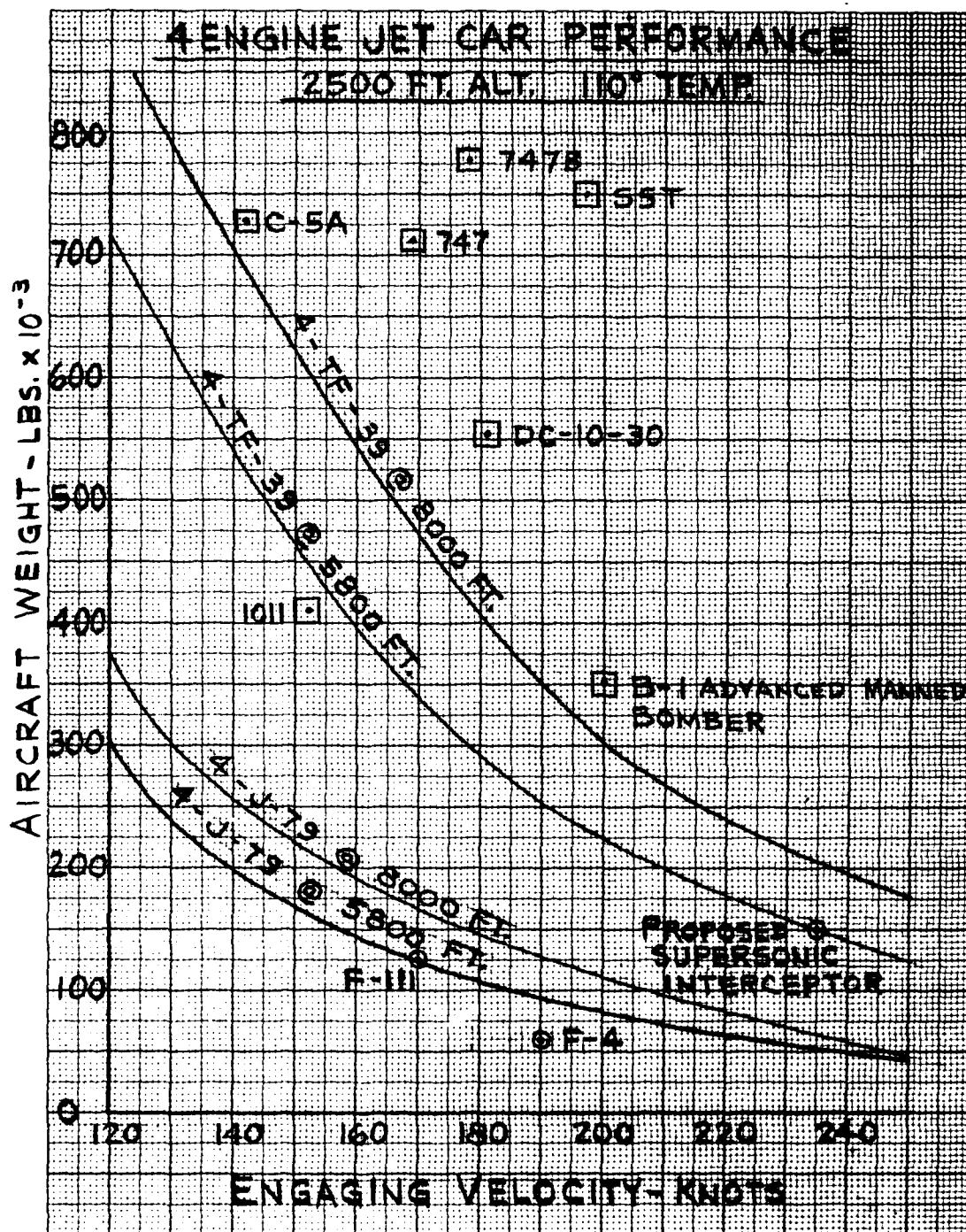


Figure 52. 4 Engine Jet Car Performance  
(2500 Ft. Alt., 110° Temp.)



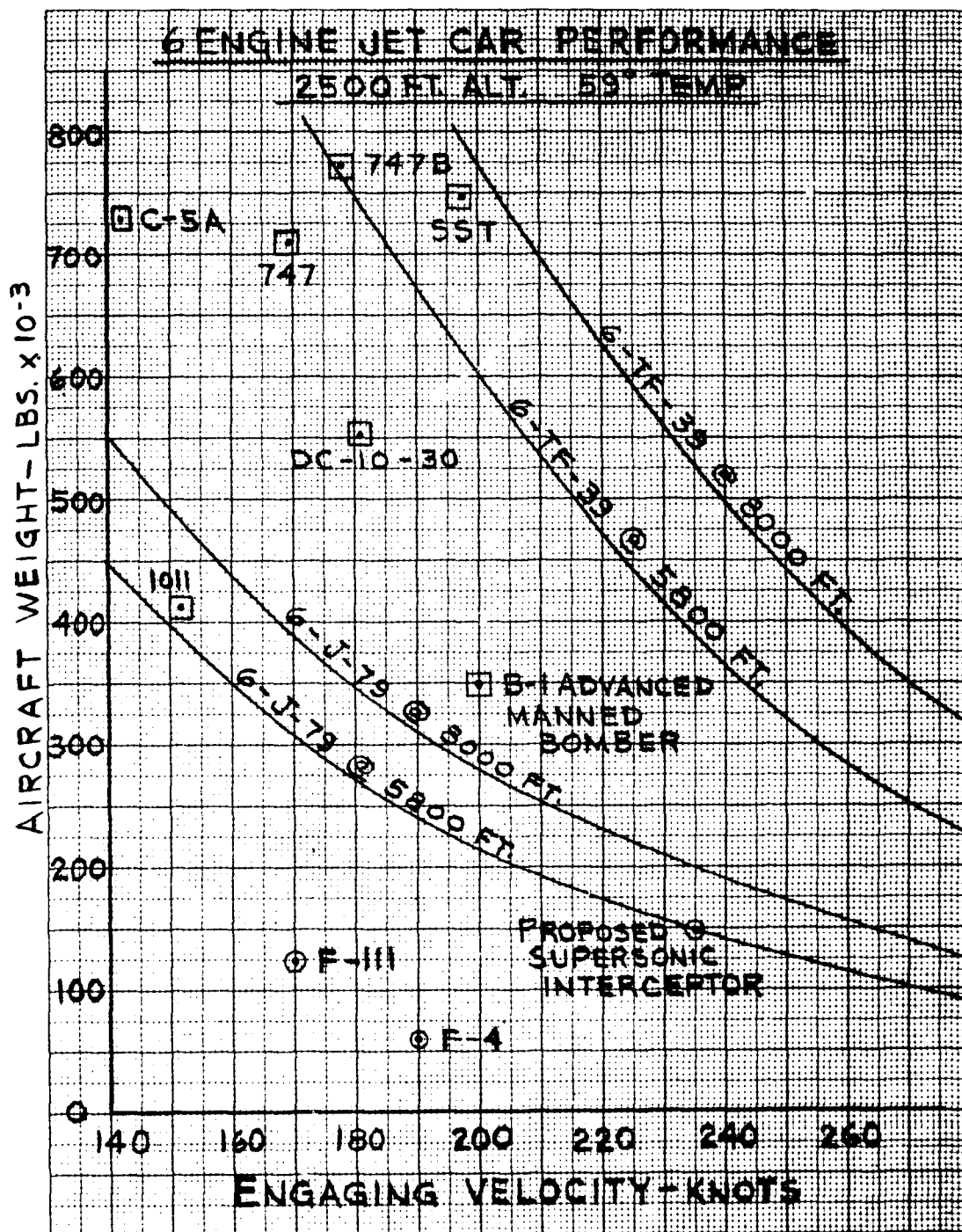


Figure 53. 6 Engine Jet Car Performance  
(2500 Ft. Alt., 59° Temp.)

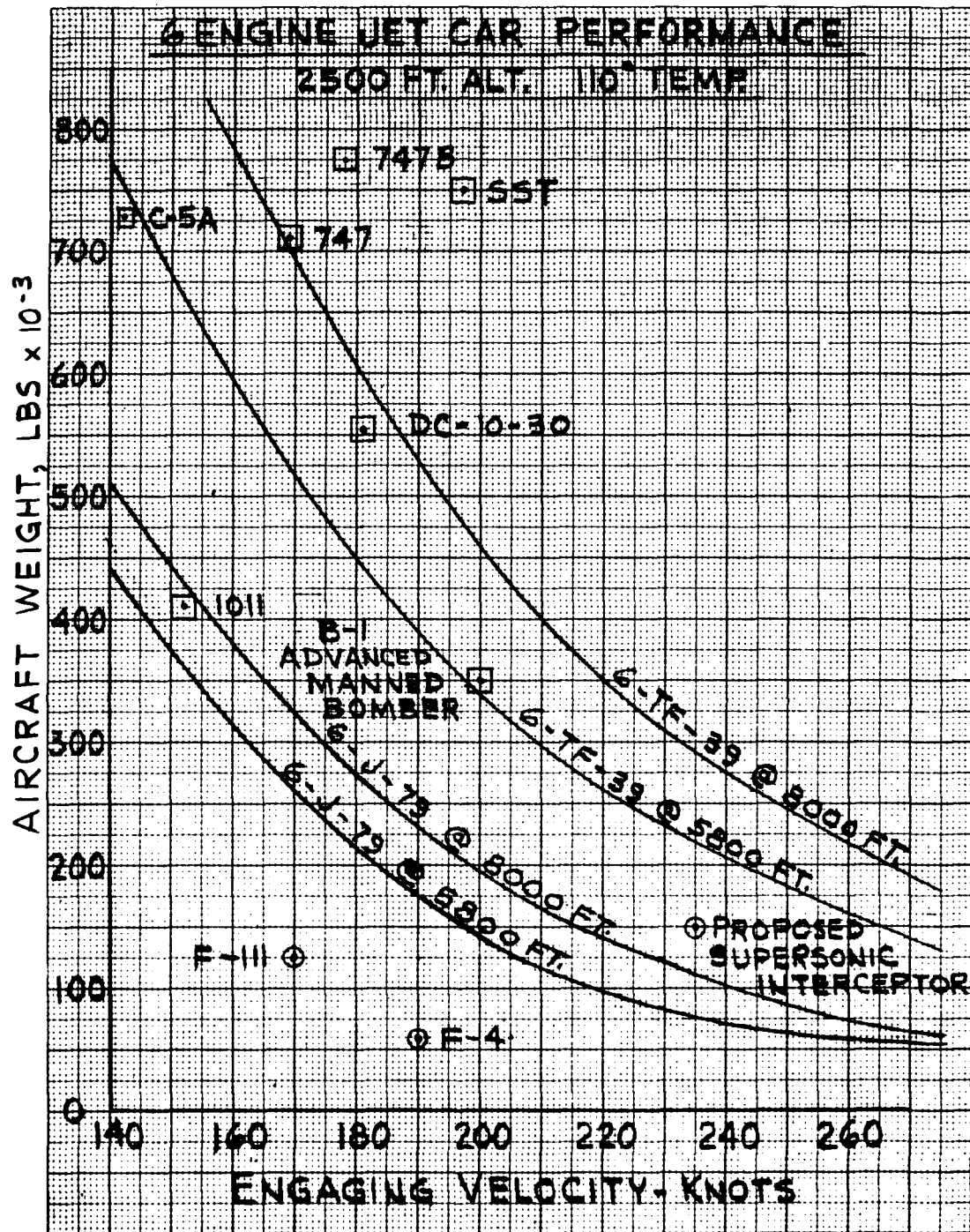


Figure 54. 6 Engine Jet Car Performance  
(2500 Ft. Alt., 110° Temp.)

## 7. SUMMARY OF ALTERNATE METHODS

a. As discussed in the preceding paragraph, utilizing J79-5 and TF-39 engines in the conventional grouping of four can generate the requirement for extending the runway at the battery end for upwards to 2000 feet. The estimated cost for this extension which includes the guide beams is \$364,800 and represents the most costly but the most practical way of meeting the full weight and speed requirement assuming that this is desired.

b. An additional source of thrust could be added to the jet car or deadload frame. This additional source conventionally takes the form of solid propellant rocket motors or JATO units but these prove to be expensive when even small thrust levels are considered.

c. Another method of supplementing thrust would be the addition of two of the same type of engines to the existing cars. This alternate, however, provides for complexity of design through the addition of two more engines and would also add considerably to the maintenance time due to the relative inaccessibility of the inboard engines.

## SECTION VI

### GUIDANCE SYSTEMS

#### 1. OBJECT

The object of this section of the study is to determine the optimum guidance system for the test facility. The determination is based on cost effectiveness and operational considerations with special attention given to the requirement to operate alternately with live aircraft and deadloads on the same runway. A range of systems was considered, both electronic and mechanical.

#### 2. ELECTRONIC SYSTEMS

Any electronic guidance system that may be used for jet car guidance will consist of:

- a. A method to generate a reference signal.
- b. A control circuit to determine the error, or deviation, from the reference.
- c. A servo system to convert the error signal into forces for car guidance.

It would appear that the servo system would need an electro-hydraulic system to develop forces of sufficient magnitude at rates fast enough for adequate control. The use of such a system would necessitate a hydraulic power source operating on the jet car and independent of any fixed facilities. The hydraulic pump could probably be mounted on jet engine accessory pad with the necessary filters, reservoirs, etc., mounted somewhere near the front end of the car. The hydraulic power would be fed through an electro-hydraulic servo valve to operate actuators connected to the steering linkage. The design of the hydraulic system is straight forward and only needs to follow state-of-the-art practices.

The control circuit that accepts the reference signal and generates any error signal, or corrective signal, to operate the servo-valve is also a straight forward design problem. With the wide selection of operational amplifiers that are available the entire control circuit could be designed so it could be mounted on not more than three 4×5 inch printed circuit cards. The cards and the necessary power supplies could be packaged in a card file no larger than 6 × 6 × 10 inches and mounted in any convenient location.

The method of generating a reference signal is not as straight forward as the hydraulics and the control circuits since there are several approaches that can be used. A listing of some of the methods is:

- a. Gyro reference on the vehicle (inertial guidance).
- b. Buried wire with an induced magnetic field to be sensed on the car.
- c. Laser target.
- d. Radio frequency target.
- e. Infrared target.

The gyro, or any inertial sensor, system requires extensive ground support equipment in that the specific gyrographic guidance data must be read into the system prior to a run. The major attraction of the gyro approach is that the system is completely self-contained and does not require operating equipment at fixed locations. Use of any of the targets or the buried wire approach does require active elements at locations other than the car and results in an increased maintenance problem.

In fact, the entire concept of using electronics for guidance requires additional support equipment, increased maintenance facilities, and additional trained personnel in the test site operating group. In addition, an off the shelf system does not exist that will satisfy the requirements for the guidance of a jet car and considerable development must be conducted to obtain an operating system. Once the development of the system is completed, and the necessary service facilities established, there is the problem of having a unique system that is susceptible to serious accidents, such as an arresting gear failure. Any failures on the vehicle could result in expensive replacement costs to regain an operating test site.

In addition, none of the electronic systems considered above would be readily adaptable to use with unmanned aircraft should it be decided to use this testing mode.

The major complication envisioned in the design of an electronic guidance system is not obvious at the beginning. Assume that standard components were available for reference signal generation and control and a servo to convert the error signal for car guidance. The next design parameter to be considered is the problem of steering both the deadload and jet car together and as separate units if the method of test operations entails a separate arresting system to stop the jet car. The larger deadload, as presently envisioned, could be a modular deadload as shown in Figure 78. This particular concept shows the deadload modules coupled together in a manner characterized by a railroad train. In order for this deadload to be steerable, all of the trailing wheels behind the front steerable set would have to be pivoted in order to trail properly. As an alternate to the modular deadload, one proposed as a single unit is shown in Figure 74. With this design the front wheels would have to be steerable while the remaining

wheels must be castered. In either case the problem of vehicle steering which would be required with an electronic guidance system would add a major equipment complexity and cost factor to the basic concept. In addition, the overall reliability of the complete system would be greatly reduced by the added number of parts, the sending and receiving of the electronic signal, the transmission of that signal to the mechanical or hydraulic steering mechanism, and the final step of having the deadload and jet car responding successfully to the intelligence of the entire network. The primary purpose of the facility is to test arresting equipment at desired weights and end speeds, not tracking and guiding the test vehicles to the arresting gear.

### 3. MECHANICAL SYSTEMS

#### a. Non-flush

The most common means of deadload and jet car guidance in operation at the present time is two "I" beams mounted parallel on top of the track surface. This is the NATF system. Special slippers or guides on the underside of the deadload and jet car are loosely constrained by the top flange of the "I" beam. This provides the necessary lateral and vertical restraint necessary for adequate guidance.

Consideration was given to this on top of the runway type of installation since it would result in less initial cost. The utilization of the non-flush guidance system, however, would require that it be removed when changing from deadload to aircraft operations and reinstalled when deadload operations are resumed. The original cost savings would more than be erased by the expenditure of manhours required in the removal and reinstallation operations inherent in this type of guidance system.

#### b. Flush

A mechanical guidance system in use by this contractor consists of two parallel "I" beams in a flush installation having the top surface of the runway similar to that shown in Figure 55. The beams are anchored or keyed into the concrete in a manner consistent with the loading expected. Inverted "T" section blades mounted on the underside of the deadload and jet car engage the slot between the upper beam flanges to provide the necessary lateral and vertical restraint. This guidance system has been utilized on an existing runway for deadload testing and live aircraft operations have been conducted on the same runway.

For the flush type installation several structural shapes were considered:

##### (1) Standard Structural Shapes

Standard "I" beams, channels and angles installed in such a manner as to provide the necessary slot between the flanges were considered. From the standpoint of initial cost, standard structural shapes appear most desirable. In the case of wide flange "I" beams and channels, however, they are undesirable due to their lack of structural integrity when operating with high pressure tires.

The 475 psi tire loading which is currently on the proposed supersonic interceptor would impose a bending load at the junction of the unsupported upper flange and the web which would exceed the yield strength of the material. The same would apply to standard structural channels. Standard angles were



Figure 55. Flush Rail Jet Car Track

also considered which would eliminate the bending moment; however, this would present a safety hazard since the vertical retention feature of the guidance system would be removed.

## (2) Special Structural Shapes

Specially extruded structural shapes adding material in the area of the upper flange to increase the section modulus were considered. See Figures 56 and 57. A major steel supplier was then contacted for price and delivery information. Being a special shape, an investment in rolls is required in the amount of \$37,171.00 with a nine month delivery. Originally a verbal delivery for the steel was quoted as an additional nine months. This contractor considered that this 18 month total delivery time would be unacceptable to the government and therefore investigated the use of modified standard shapes. In the interim the vendor indicated that the steel can be delivered (from their San Francisco mill) in 8 to 12 weeks after the rolls are manufactured; this is considered to be an acceptable delivery schedule. A detailed cost comparison shows that the procurement of special shapes for the guide rail would result in an expenditure of \$221,760 as compared to \$116,602 for the standard shapes. However, an estimated \$55,000 would have to be expended to modify the standard shapes to have them ready to be installed in the concrete. It is assumed that the cost for the actual placement of either type of beam into the concrete would be almost identical. Therefore, the most economical guide beams as determined in this study are a modification of the special zee section proposed and quoted originally. The quotation and subsequent correspondence can be found in Appendix I.

## (3) Modified Standard Shapes

These shapes were considered as an acceptable alternate to the special shapes discussed previously. The use of the conventionally used 10 inch wide flange, 49 pounds per foot, "I" beams were considered first. These would be modified by removing most of the inner, upper, and lower flanges to decrease the bending stresses at the junction of the flange and web through a decrease in the moment arm. See Figure 58. This beam subsequently proved to be inadequate structurally when a two "g" upload of the 720,000 pound deadload was considered. A similar modified shape but weighing 66 pounds per foot was subsequently found to be adequate for the same loading.

### c. Removable Section Concept

In the event that it is desired to test with the deadload unguided just prior to, and after engagement, the concept of removable track sections was developed. It consists of a square or rectangular steel tube slotted to accept the guide. The tube is restrained laterally by angle and vertically by bolts into a section of "I" beam buried in concrete as shown in Figure 59.

The design was found to be structurally inadequate. A modification to this concept, however, was used in the design of that section of the guide beams which is used to unlatch the retractable guides from the track so that the deadload may run unguided.

## 4. ANALYSIS OF GUIDANCE SYSTEMS

The various guidance systems under consideration were rated in a comparative analysis as was used in the propulsion systems analysis. See Appendix



III. As was the case with the propulsion systems ratings, safety was considered more important than any other factor.

Again the rating parameters were first compared to establish an order of importance. After this step a numerical rating was given to the various degrees of the parameters and a relative importance factor assigned. The ratings are based on a scoring system of 1 - 10 whereby the highest score is the optimum system. The order of importance, the ratings, and the relative importance factors are as follows:

<u>Definition</u>	<u>Rating</u>	<u>Relative Importance Factor</u>
1. Safety		
a. maximum	9-10	11
b. moderate	5-6	
c. minimum	1-2	
2. Structural Integrity		
a. high	9-10	10
b. moderate	5-6	
c. low	1-2	
3. Initial Cost		
a. low	9-10	9
b. moderate	5-6	
c. high	1-2	
4. Development Required		
a. none	9-10	8
b. some	5-6	
c. extensive	1-2	
5. Compatibility with live aircraft		
a. high degree	9-10	7
b. moderate degree	5-6	
c. low degree	1-2	
6. Reliability		
a. high	9-10	6
b. medium	5-6	
c. low	1-2	
7. Cost of Operation		
a. low	9-10	5
b. moderate	5-6	
c. high	1-2	



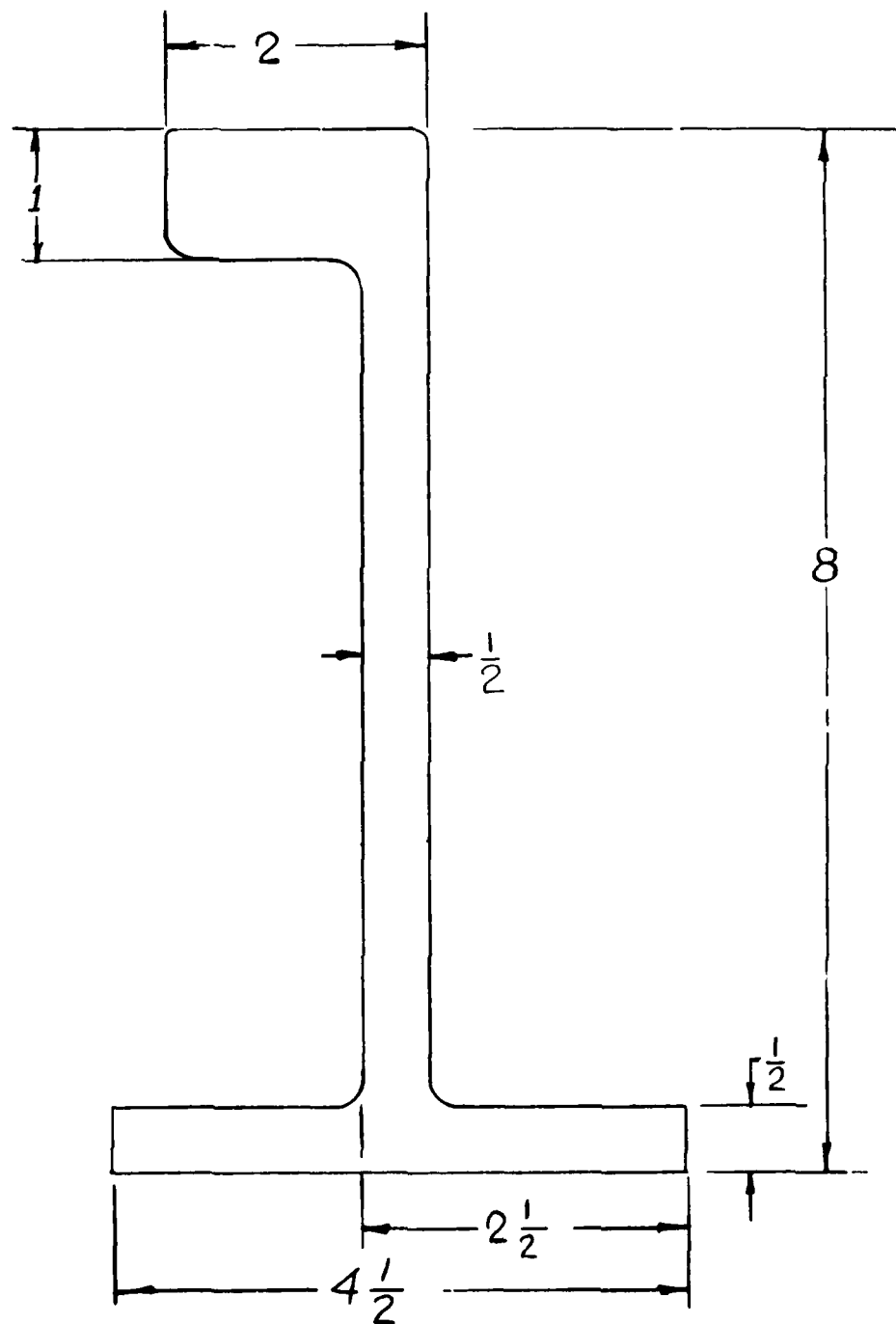


Figure 57. Special Shaped Guide Rail

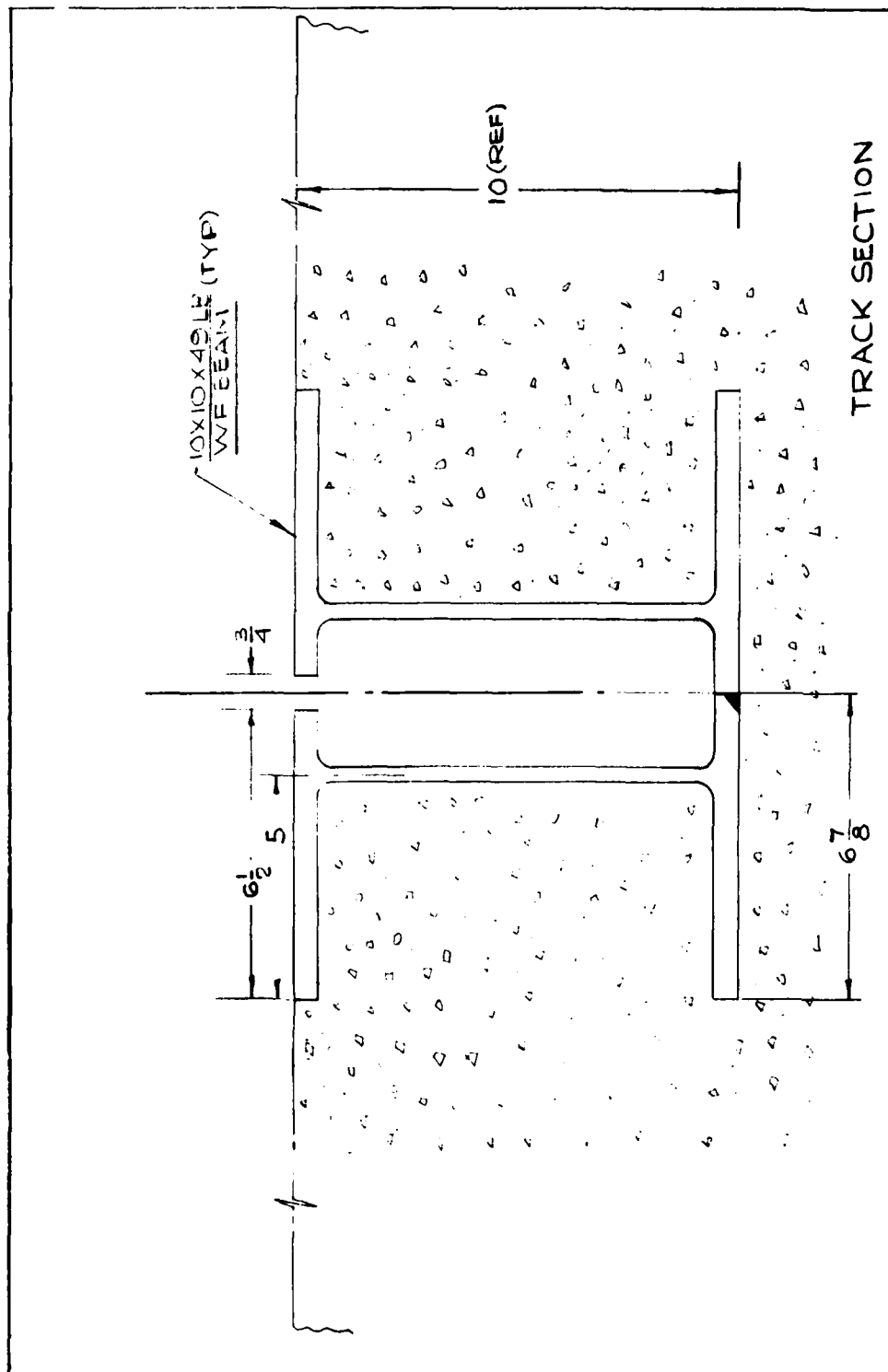


Figure 58. Modified Standard Beam

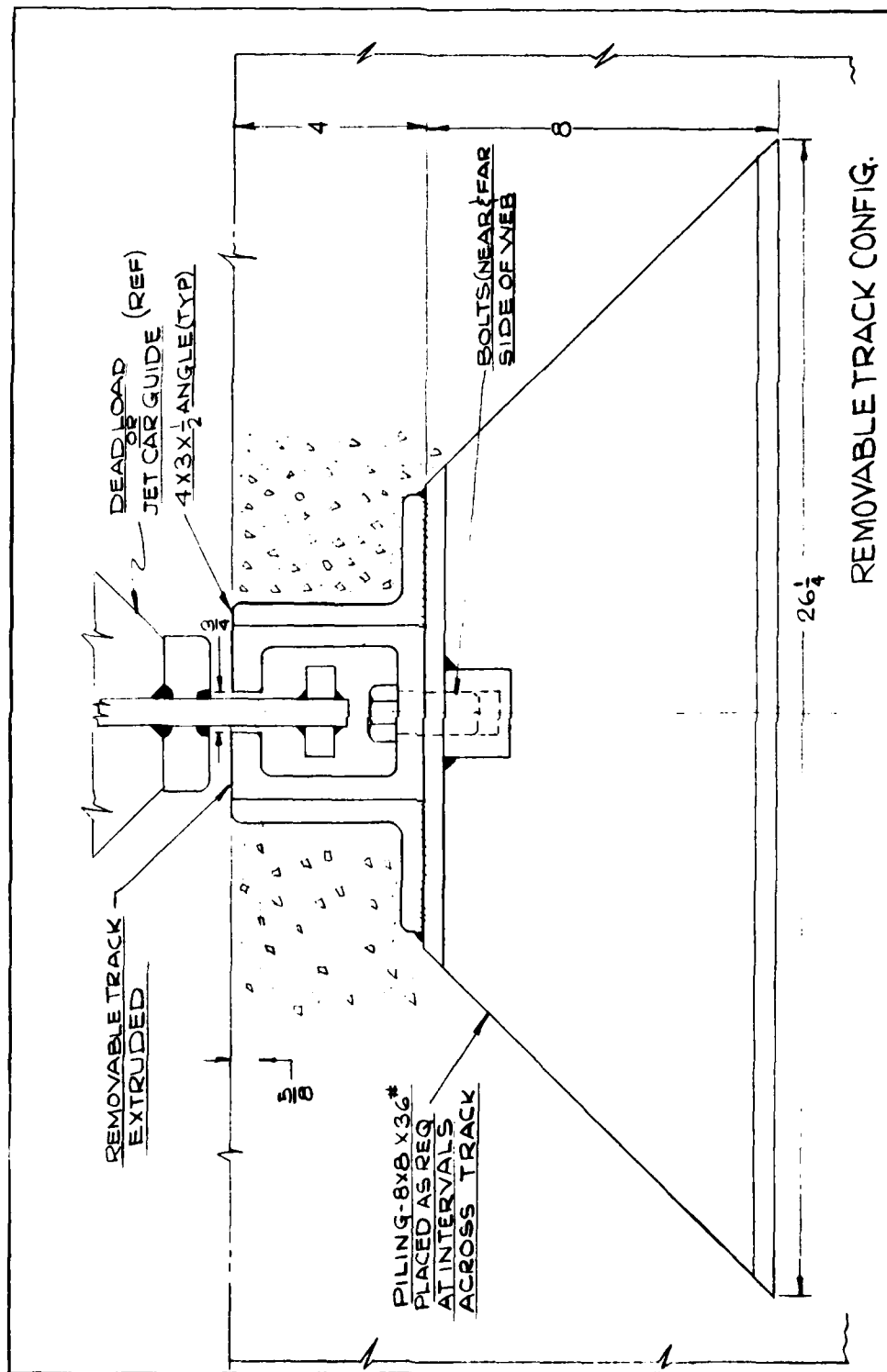


Figure 59. Removable Track Configuration

<u>Definition</u>	<u>Rating</u>	<u>Relative Importance Factor</u>
8. Maintenance		
a. easy	9-10	4
b. moderate	5-6	
c. difficult	1-2	
9. Number of operating personnel		
a. none	9-10	3
b. medium number	5-6	
c. high number	1-2	
10. Type of operating personnel		
a. unskilled	9-10	2
b. semi-skilled	5-6	
c. skilled	1-2	
11. Type of Vehicles Required		
a. non-steerable, simple	9-10	1
b. steerable, complex	1-2	

The guidance systems were then compared against each other for each parameter and an order of desirability established as follows (see Table IV):

1. Flush rail
2. Non-flush rail
3. Buried wire
4. Radio guidance
5. Inertial guidance
6. Laser guidance

Table IV shows quantitatively that the least desirable guidance systems are those that would utilize buried wire or radio, inertial or lasers as the basic guidance method. Although not directly evident in this table, the basic reason for their relative undesirability is the requirement for the added major complication of steerable deadloads and jet car vehicles. The basic disadvantage of the non-flush mechanical guidance system is the requirement to remove the rails for aircraft operation and the subsequent re-installation when deadload operations are desired. This concept would result in the utilization of many days and man-days of site preparation which would be non-productive for actual test operations. The flush rail is the system recommended to fulfill the projected test requirements of the AFFTC; this system potentially has one problem of concern. This

TABLE IV  
GUIDANCE SYSTEMS EVALUATION

	Safety	Structural Integrity	Initial Cost	Development Required	Compatibility with Aircraft	Reliability	Cost of Operations	Maintenance	Number of Operating Personnel	Type of Operating Personnel	Type Vehicle Required	TOTAL
Importance Factor	x11	x10	x9	x8	x7	x6	x5	x4	x3	x2	x1	
Flush Rail	110	100	72	80	63	60	40	40	21	18	20	624
Non-Flush Rail	110	100	90	80	7	60	10	36	21	18	10	542
Buried Wire	55	20	45	48	70	30	25	24	18	4	4	343
Radio Guidance	55	10	18	56	70	42	10	12	18	2	1	294
Inertial Guidance	44	10	9	16	70	30	5	8	15	2	1	210
Laser Guidance	33	10	9	8	70	12	5	4	18	2	1	172

is the possible incompatibility of high pressure tires rolling along or over the slot between two adjacent rails. This is discussed in more depth in paragraph 5.

## 5. COMPATIBILITY OF THE PROPOSED GUIDANCE SYSTEM

Recognizing that the mission success of the AFFTC will require the successive operation of deadloads and manned aircraft with minimum delay, the utilization of two parallel, flush mounted, special "Z" shaped structural guide beams is recommended. Past experience with aircraft nose and main wheel tires operating on a similar guidance system with a nominal one and one quarter inch gap between the beams did not show any adverse effects on the aircraft tires. Since that time aircraft tire pressures have increased to the 475 psi range. As far as can be determined there is no data available relative to high pressure tires operating along or over a slot at high speed. As part of this design study one of the major aircraft tire manufacturers was contacted in an attempt to interest them in simulating this condition in a tire testing laboratory. This particular manufacturer was not interested.

The utilization of a three-quarter inch wide slot, as opposed to some other dimension, is based on the use of this width slot in the guide rail on the CE catapults. These rails or track sections are aluminum extrusions and have been subjected to nose wheel loading from F-8, A-4 and F-104 type aircraft at speeds up to 230 knots. The three quarter inch dimension is actually considered to be marginal considering the design of the deadload and jet car guides.

When launching aircraft with this catapult system, the nosewheel rests on the shuttle during the full catapult power stroke. At a predetermined stroke, depending on the end speed required and the power setting used, the power is reduced to idle. This allows the aircraft to accelerate past the shuttle. Ideally the aircraft rotates at the proper time which causes the nosewheel to lift off the shuttle and otherwise have the aircraft become airborne without excessive post launch ground roll. This is an ideal situation which is not always attained even with proficient pilots. In this case, the aircraft rotates late which causes the nosewheel to run off the front of the shuttle and make contact with the track two or three feet ahead of it. The nosewheel then rides on the aluminum guide rail or track slot for some distance until the aircraft rotates and is airborne. There have been many instances where the nosewheel runs along or over the slot in the guide rail or track with no adverse effects on the track or nosewheel tire.

Further, it would seem that higher pressure tires would reduce rather than increase the potential problem, i.e., the higher pressure tire has more rigidity with subsequently a lesser tendency to extrude into the slot.



SECTION VII  
COST SCHEDULES

1. JET CAR FACILITY

The following is a summary of the cost estimates generated as part of this study; the estimates were made by this contractor's estimating department:

a. Dual Flush Guide Beams

<u>Item</u>	<u>Total Estimated Cost</u>
8000 ft. Keel Strip & Dual Flush Guide Beams	\$1,200,000.00
2000 ft. Runway Extension	364,000.00
J79 Jet Car (Engines & Wheels GFE)	116,000.00
TF-39 Jet Car (Engines & Wheels GFE)	157,000.00
681,600 pound Modular Deadload	78,000.00
Holdback Assembly	5,600.00
Air Starter Unit	57,000.00
Warning Lights	7,200.00
Portable Electric Power Unit	22,000.00
Operations Trailer	5,800.00
Fuel Trailer	10,000.00
Control System	30,000.00
	<u>\$2,052,600.00</u>

b. Dual Non-Flush Guide Beams

<u>Item</u>	<u>Total Estimated Cost</u>
8000 ft. Keel Strip & Dual Non-Flush Guide Beams*	\$1,365,000.00
2000 ft. Runway Extension	364,000.00
J79 Jet Car (Engines & Wheels GFE)	116,000.00
TF-39 Jet Car (Engines & Wheels GFE)	157,000.00
681,600 pound Modular Deadload	78,000.00
Holdback Assembly	5,600.00
Air Starter Unit	57,000.00
Warning Lights	7,200.00
Portable Electric Power Unit	22,000.00
Operations Trailer	5,800.00
Fuel Trailer	10,000.00
Control System	30,000.00
	<u>\$2,217,600.00</u>

\*Based on the use of standard 10WF66 pound beams versus special "Z" shapes for the flush guide beams at 23.64 pounds/foot.

## 2. ROCKET CAR FACILITY

<u>Item</u>	<u>Total Estimated Cost</u>
8000 ft. Keel Strip & Dual Flush Guide Beams	\$1,200,000.00
Rocket Car (Wheels GFE)	55,000.00
681,600 pound Modular Deadload	78,000.00
Holdback Assembly	5,600.00
Warning Lights	7,200.00
Operations Trailer	5,800.00
Control System	15,000.00
Temperature Conditioning Building	75,000.00
Rocket Storage Buildings	50,000.00
	<hr/>
	\$1,491,600.00

## 3. FACILITY OPERATING COSTS

### a. Jet Car

A current contract between this contractor and an agency of the Swiss Government establishes the rental of one active runway which is a jet car operating site at a fixed price of \$2,094.00 per day. This includes the labor of thirteen operating personnel plus the cost of consumables at \$346.00 per test event.

### b. Rocket Car

In Section V, paragraph 5, a cost estimate of \$174,375.00 per test event was established for a 3,000,000 pound second thrust requirement.

## SECTION VIII

### ALTERNATE USES FOR THE FACILITY

In addition to the proposed primary uses of the facility as expanded, the facility would also lend itself to several other uses as discussed below. It would also be capable of using for whatever purpose not presently conceived, weights and speeds and therefore energy levels in an order of magnitude ten to twelve times greater than that of any other test facility known to exist. Some of the alternate uses for the facility are the following:

#### 1. PARACHUTE TESTING

The weight and velocity capability of the proposed jet car/deadload facility may prove feasible for testing parachutes. The existing sled type facilities at Holloman is suitable for testing parachutes six feet in diameter and smaller and other deceleration devices. The advantage of the proposed facility is the high weight available which would be more commensurate with aircraft weights for fighter and bomber type aircraft than any existing facility.

The proposed facility jet car and deadload may be used as a test vehicle for landing parachutes designed for future aircraft. The weights and velocities, which would be available, appear well suited to high speed testing of such a parachute prior to actual use in an emergency landing. Existing landing chute designs have evolved from aircraft to aircraft, rather than being an optimized design for a specific aircraft. This has been largely due to the lack of a suitable test facility capable of testing appropriate weights and velocities to ensure drag and stability performance as well as structural integrity prior to deployment from an aircraft. The proposed facility would permit design of a specific parachute assembly with minimum weight and volume. Testing could include determination of basic performance parameters such as drag, stability, and structural integrity as well as deployment from a stowage compartment by utilization of a mock-up airframe section. It should be noted that satisfactory and reliable deployment of landing parachutes is often a critical problem in the early life of a new type aircraft. Other parachute test applications relate to testing of large deceleration chutes for various payloads.

Considerations to be taken into account in evaluating the proposed facility for parachute testing are:

- a. Suitable attachments on the jet car or deadload would be required. Strength of the attachments should be capable of withstanding a one g deceleration force. This, however, should pose no real problem.

b. The height of the attachment point may pose a problem in providing adequate ground clearance for larger chutes. It should be noted that "ground effect" will normally result in the chute flying with its lower skirt above the ground a distance equal to 1/4 the inflated diameter of the chute.

c. The overturning moment imposed on the jet car or deadload may be very high, depending on the line of action of the chute drag in relation to the vehicle c.g. A means of reacting this moment must be provided.

d. The wake effect of the test vehicle may not be comparable with the aircraft for which the parachute is to be used. A long riser may be used to overcome wake effects.

## 2. EJECTION SEAT TESTING

Tests of aircraft ejection seats have been conducted on the arresting gear test site at the Naval Air Test Facility, Lakehurst, N.J.

A specially constructed deadload consisting of a cockpit section of an aircraft mounted on a carriage was manufactured by this contractor. See Figure 60. This carriage was equipped with the necessary slipper guides to engage the track and hardware at the aft end for attachment to the jet car. The deadload was pushed by and remained attached to the jet car.

Under test the jet car/deadload vehicle is accelerated to the desired velocity. At a predetermined position, on the test track, a trip wire on the deadload is cut activating the electrical system which jettisons the canopy and fires the ejection seat. The jet car/deadload vehicle continued on to the normal engine shutdown position and is brought to a halt by the trailing jet car brakes. Test velocities up to 250 knots have been attained at far less cost than those attained on a rocket track.

Canopy jettison tests have been conducted by this contractor at the company's test facility located at Georgetown, Delaware; obviously similar testing could be accomplished at the AFFTC during the lifetime of the proposed expanded facility.

In these tests an aircraft cockpit section is mounted on top of a standard jet car. See Figure 61. The test vehicle is accelerated to the desired velocity. At the engine cut-off position on the test track both the engine cut-off and canopy jettison trip wires are cut. The canopy is jettisoned with no decay in velocity due to residual thrust of the engines. The jet car is then brought to a halt by the normal trailing brakes.



Figure 60. Test Vehicle for Evaluation of Ejection Seat Equipment  
on Jet Car Test Track



Figure 61. Canopy Ejection Test Using Jet Car Test Track

### 3. AIRCRAFT CRASH - INVESTIGATION TESTING

This contractor has utilized the company's test facility to develop and evaluate a crash resistant fuel system. For these tests an aircraft wing section was mounted on a standard deadload as shown in Figure 62. This deadload was accelerated by a jet car into a high "g" energy absorber.

In the case of aircraft crashes on take-off or landing as a result of catapult or arresting gear failure, the U. S. Navy utilizes the facilities of NATF to duplicate as closely as possible the conditions prior to the crash. This is done as closely as safety will permit in order to determine, if possible, the exact cause or causes of the crash.

It would be possible to evaluate aircraft structures under emergency or crash conditions either by an assembly, subassembly, or component basis. Passenger and aircrew safety devices could also be evaluated at the AFFTC.

### 4. AERIAL DELIVERY SYSTEM TESTING

This contractor has utilized the company test facility to develop a "ground proximity extraction system" method of cargo delivery.

The proposed facility could also be utilized to test any future proposed system for extracting cargo from aircraft on a fly-by, no landing basis.

A standard deadload could be modified with an elevated platform of a length and width which duplicates the cargo compartment floor of a C-130 or other cargo aircraft. This deadload could be attached to and pulled by a jet car as shown in Figure 63. Tests can be conducted at various velocities to simulate extraction of cargo from an aircraft in flight. Once the cargo had been extracted jet engine cut-off can take place and the jet car/deadload combination engage an energy absorber which would bring it to a stop.

### 5. AERIAL RECOVERY SYSTEMS

This contractor has also conducted tests simulating aerial recovery parachute engagement. Similar testing could be accomplished at the AFFTC.

In this test arrangement the parachute is suspended inverted from a tower above the jet car track. A large fan can be utilized to keep the chute inflated. Aerial recovery poles and a winch are mounted on the jet car similarly to that shown in Figure 64, after the jet car is accelerated to the desired velocity. The hooks on the poles engage the parachute which pull a weight from the tower. The hooks are connected through a loop to the energy absorbing winch line thus simulating an aerial recovery. The jet engines are then cut off and the jet car stopped by the means provided.

Other tests could be conducted on aerial recovery winches by accelerating deadloads equipped with a hook which engage a loop connected to the energy absorbing winch line.



Figure 62. Aircraft Structure Mounted on Deadload for Crash Investigation Test on Jet Car Track





Figure 63. Simulating Aerial Extraction from Aircraft in Flight on  
Jet Car Test Track



Figure 64. Simulating Aerial Recovery Parachute Engagement on  
Jet Car Test Track

## 6. RECOVERABLE SPACE VEHICLE FACILITY

As the recoverable and re-usable space vehicles presently under design evolve and become reality so will the requirement for a recovery area for test and operational vehicles.

The arresting gear test facility will be ideally suited to meet this requirement. The runway will be of sufficient length and the dry lake bed would provide additional recovery area if required. The arresting gear installed can be connected to a net type barrier and the space vehicle arrested in the event of an emergency or as an operational procedure.

## 7. LANDING GEAR DYNAMIC TEST FACILITY

A Landing Gear Dynamic Test Facility (LAGDYN) was conceived several years ago as an improved method of evaluating total aircraft landing gear system performance. The LAGDYN system is another approach to more sophisticated dynamometers in that a solution to the basic test requirement would be to move the test gear relative to a stationary surface such as an existing runway rather than move the surface (dynamometer flywheel) with respect to the stationary gear. The proposed system consists of one or more carriages which simulate aircraft with different main gear wheel loading and different accelerations. The concept is similar to the utilization of a deadload except that the carriages would be for the evaluation of existing and proposed landing gear systems. The carriages could have the kinetic energy dissipated at the end of a test event by either an operational aircraft arresting gear or an arresting gear currently under development testing. It is obvious that the proposed deadload test facility could be used in conjunction with or as a supplement to a LAGDYN facility.

## 8. OTHER

The proposed facility may also be adapted to tests in the following areas:

- a. Moving gun platforms.
- b. Physiological testing.
- c. Long stroke acceleration and deceleration testing of aircraft components.

## SECTION IX

### CONCEPTUAL DESIGN OF DEADLOADS/JET CAR

#### 1. BASIC CONCEPTS

##### a. Basic Deadload

A basic deadload is a steel frame dolly suspended on aircraft type wheels and tires. It is equipped with an aircraft type arresting hook which can be installed to engage an overhead arresting gear pendant or pick one up off the runway surface. See Figure 65. Guidance is provided by one or more inverted "T" type blades which engage a slot in the runway. Basic instrumentation is provided in the form of a strain gage on the hook and an accelerometer. Provision is made for an onboard battery powered electrical system.

The size and shape of a deadload can for the most part be tailored to suit the needs of the user. The normal shape is rectangular with a low profile. Deadloads have also been constructed in the shape of and to represent a class or type of aircraft. See Figure 66.

The primary function of a deadload is to simulate the weight and speed of an aircraft engagement into an arresting gear. In this way the necessary performance data may be obtained and possible malfunctions detected without risk of damage to aircraft or injury to the pilot.

In some isolated cases, the deadload has been constructed to simulate the moment of inertia and C. G. location of a particular aircraft as well as the weight.

#### 2. APPROACHES TO DEADLOAD CONCEPT BASED ON JET CAR PROPULSION

##### a. Jet Car Pushing and Not Part of the Deadload

The most common method of accelerating a deadload in use today is a multi-engine jet car. Special extensions normally built into the chassis, in the front of the car, act as push rods. These rods engage tubular extensions on the rear of the deadload. With the jet car restrained by a holdback device the engines are started and the power is adjusted to the value required for the desired velocity. At a predetermined location in the acceleration stroke the jet engines are shut down and the jet car is stopped by means of trailing brakes or a separate energy absorber. The deadload, no longer connected to the jet car, continues on into the arresting gear at the desired engaging velocity which is less than the velocity attained by the jet car due to a coast down velocity decrease.

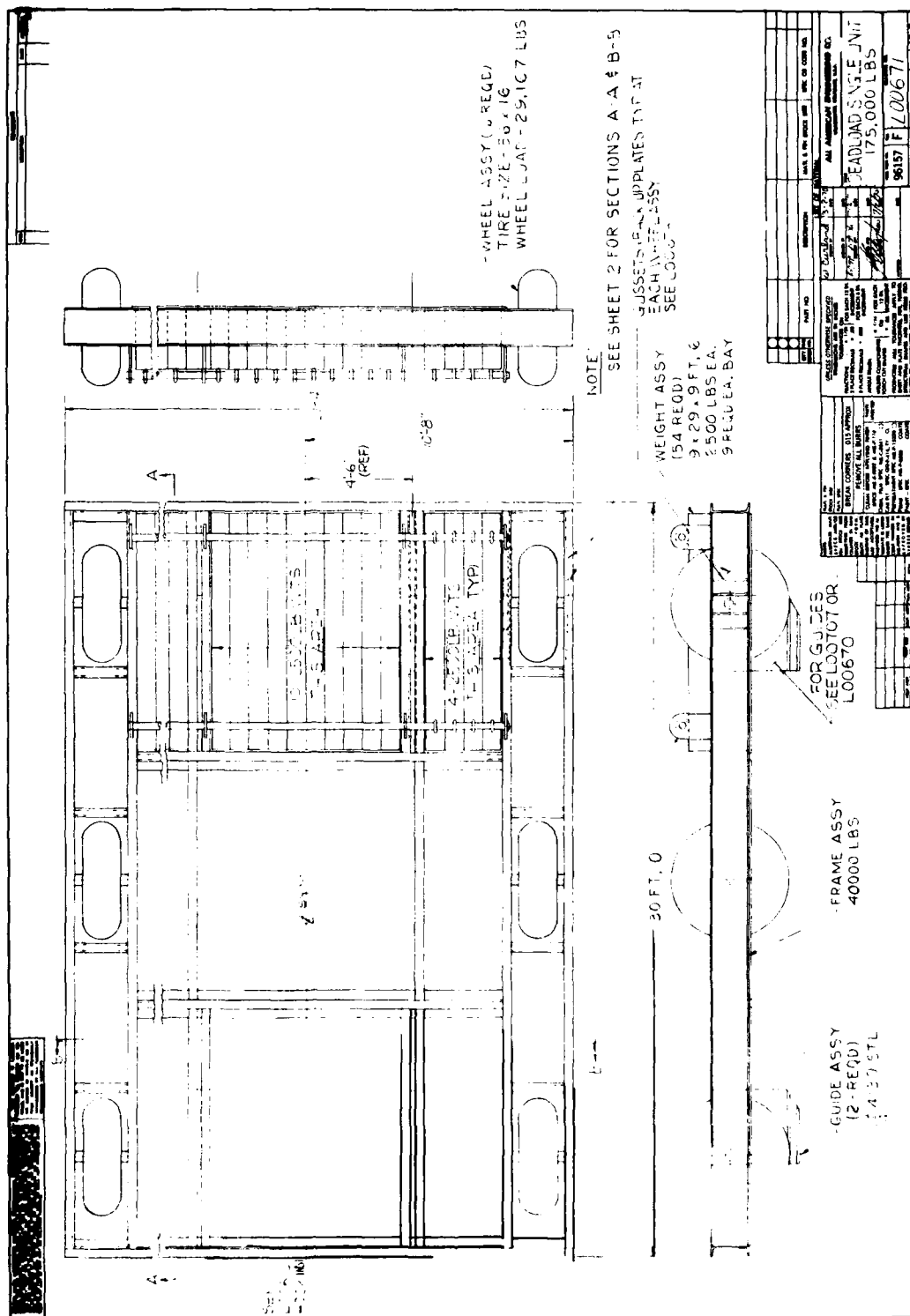


Figure 65. Dead Load Single Unit - 175,000 Lbs.



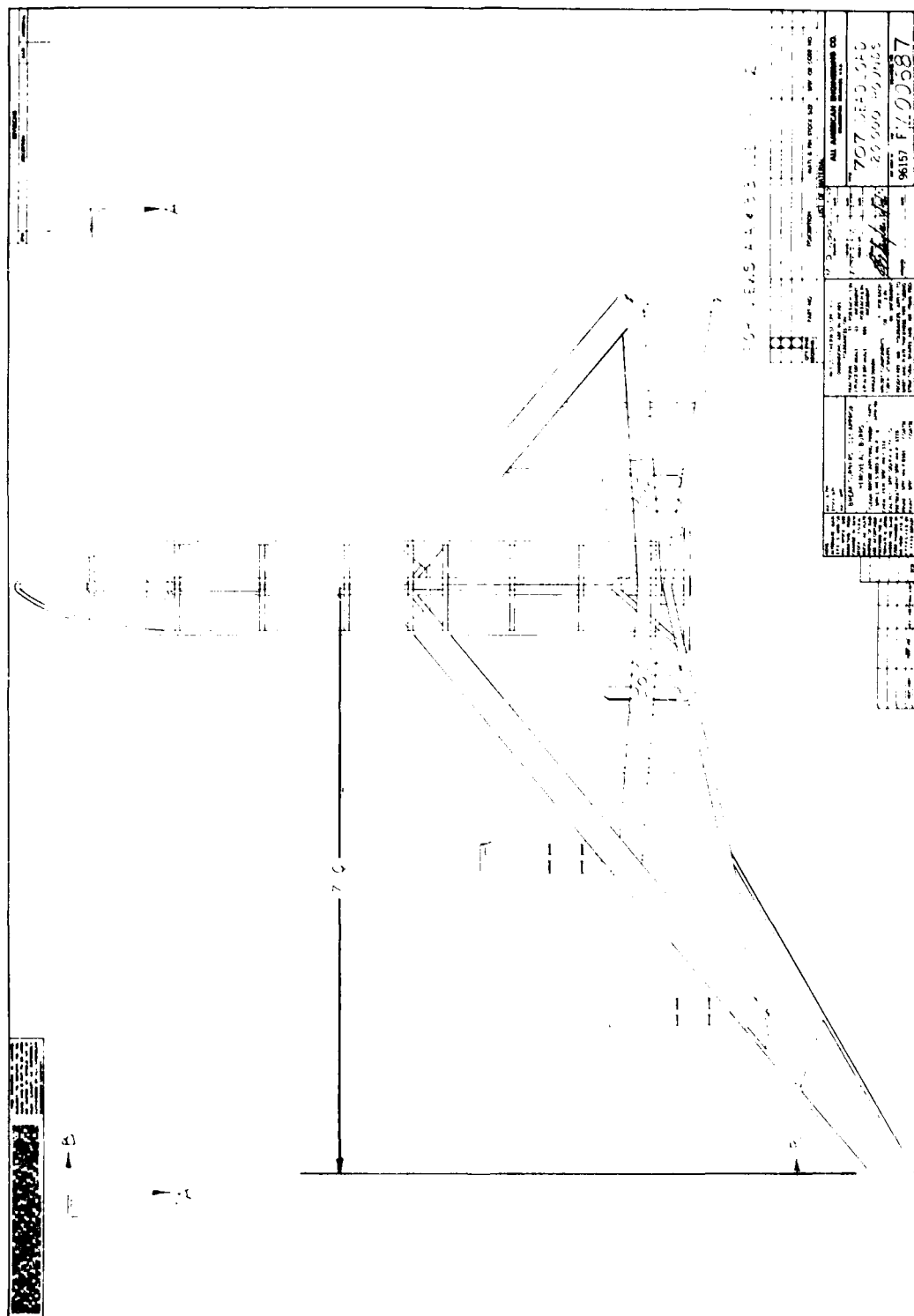
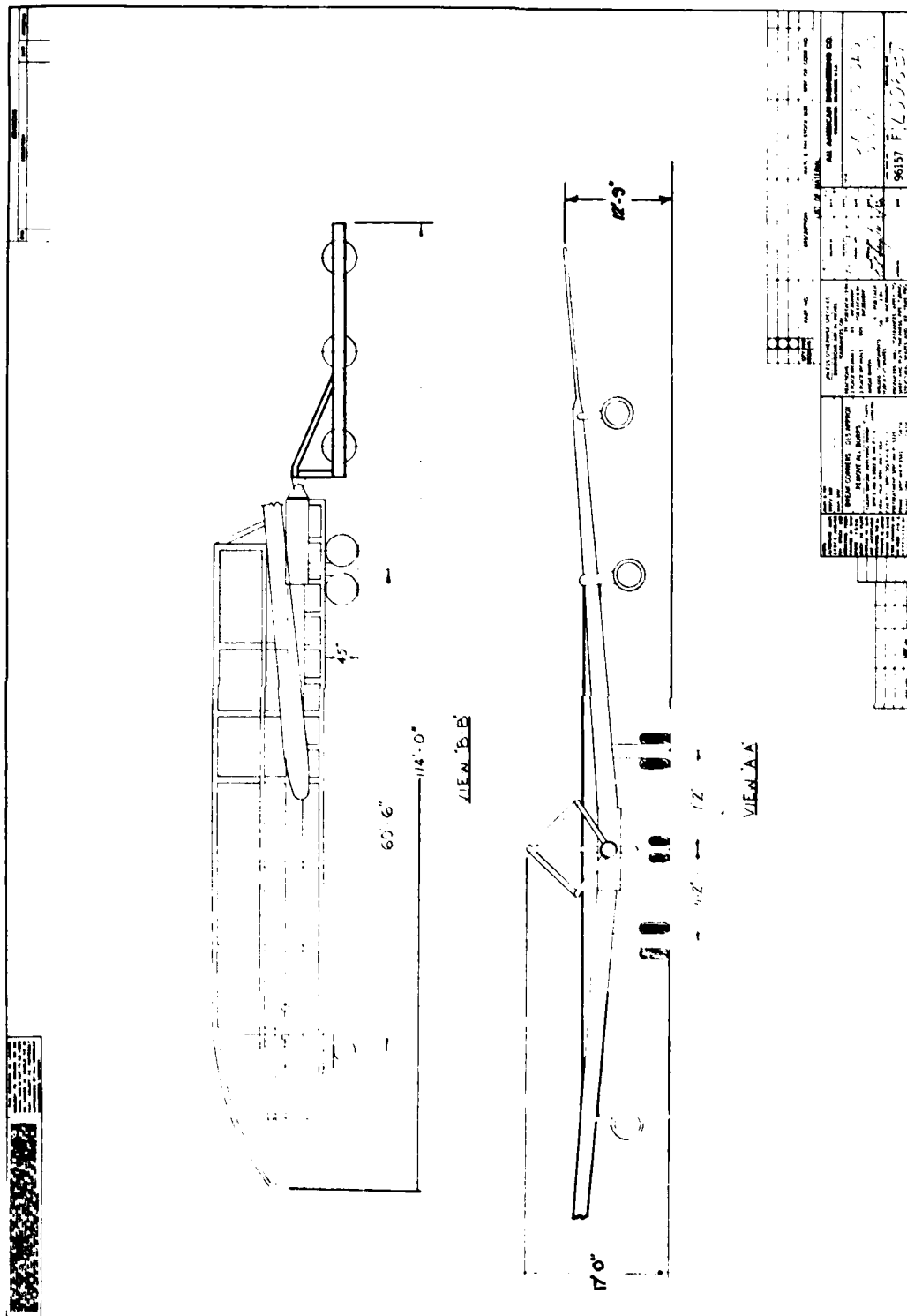


Figure 66. 707 Dead Load



"Figure 66---Concluded"



There are several disadvantages to this method of accelerating the deadload which are listed as follows:

- (1) Additional acceleration stroke is required or available stroke reduced to allow for arrestment of jet car.
- (2) Drag brakes or a separate energy absorber are required to stop the jet car.
- (3) A velocity greater than the desired engaging velocity must be reached to allow for coast down after engine shut down.
- (4) Due to (3) above greater engine power is required for a given velocity than would normally be required; this affects operating cost and engine maintenance requirements.

The advantages are:

- (1) Less chance of damage to jet car in event of missed engagement or arresting gear malfunction.
- (2) Greater flexibility in operations with respect to light weight deadloads.

b. Jet Car Pulling and Part of Deadload

Another method of accelerating the deadload is having the jet car ahead of and pulling the deadload. In this configuration the basic operation of the jet car is the same as in the jet car pushing the deadload. The principal difference is that the jet car is attached to and arrested as part of the deadload.

The advantages of this configuration are:

- (1) No separate arresting means are required for the jet car.
- (2) Greater range of engaging velocities due to fact that engine cut-off can be just prior to engagement thereby reducing coast down to a minimum.
- (3) Greater degree of accuracy with respect to engaging velocity as a result of engine cut-off just prior to engagement.
- (4) A power-on type aircraft engagement can be simulated by allowing the jet car to power into the engagement and be shut down or throttled back during the arrestment.
- (5) Longer accelerating stroke available thereby reducing engine power requirements for given velocity.

The disadvantages are:

- (1) Increased probability of damage to jet car as a result of missed engagement or arresting gear malfunction.
- (2) Operations cannot be conducted with weights less than that of jet car.
- (3) Jet car safety considerations would make unguided operations less desirable when compared with stopping the jet car independently.
- (4) Jet engine blast would impinge on deadload with a resulting requirement to add blast deflectors to the deadload or have extra long interconnecting rods. The addition of blast deflectors would result in decreased efficiency due to a change in the resultant thrust vector.

c. Jet Car Pushing and Part of Deadload

The third means of accelerating the deadload is to have the jet car pushing and attached to the deadload. In this configuration the operation is the same as previously discussed. The primary difference is that the hook is installed on the jet car and the jet car and deadload are arrested as a combined unit.

The advantages and disadvantages of this configuration are the same as those found in Paragraph b above, except disadvantage item #4. An additional disadvantage of this configuration, however, is the hook must be installed on the jet car. This requires additional and/or heavier structural members in the chassis of the jet car in order to withstand the loads imposed during an arrestment. This was thought to be a major structural problem when considering the arrestment of 764,000 pounds at 2 g's. A preliminary stress review, however, has shown that this is not a major problem but does require additional structural members.

d. Recommended Approach

After reviewing the advantages and disadvantages of the two approaches to the jet car/deadload acceleration methods, it was determined that the more conventional method of having the jet car push rather than pull the deadload was the optimum solution. This decision was primarily due to the requirement for blast deflectors on the deadload(s) and the resulting decrease in the net horizontal thrust component. The jet car pushing the deadload, therefore, appears to be the most practical, efficient, and economical, and therefore recommended method of accelerating deadloads.

For tests requiring a weight of 40,000 pounds, or less, the standard method of the jet car pushing described above must be used. In the 40,000 lb. to

100,000 lb. weight range one of two methods may be utilized. These are the standard procedure of detaching the jet car from the deadload or the method of the jet car pushing and attached to the deadload during arrestment. For tests in the weight ranges above 100,000 lb. the jet car pushing and attached to the deadload must be used. This latter method has been utilized successfully by this contractor in arresting gear tests.

e. Jet Car

The purpose of the jet car is twofold. In the basic configuration with the integral hook, it serves as a self-propelled deadload. It also is utilized to accelerate a deadload by pushing it separately or by towing or pushing and being part of the deadload.

The jet car is a steel frame dolly suspended on aircraft type wheels and tires. The suspension system is unsprung and non-steerable. It is equipped with an aircraft type arresting hook which can be mounted to engage an overhead arresting gear pendant or one on the runway surface. Guidance is provided by inverted "T" type blades which engage a slotted track in the runway surface. A fitting is provided for holdback or for towing of a deadload on the configuration to be utilized.

The framing provides for the mounting of four J-79 or TF-39 jet aircraft engines. See Figures 67 and 68. The engines are mounted utilizing the standard engine mounts and electrical and fuel fittings provided with the engine.

Provision is made for an on-board fuel supply as well as a battery powered electrical system. Quick-disconnect type fittings are utilized to provide external fuel and power for use during engine run-up prior to release. The necessary oil pressure gages for monitoring engine performance are mounted in a readily visible position.

The jet car utilizing J-79 engines will be covered, except for intake and exhaust areas, with .065 gage aluminum. The covers will be in removable panels to provide for ease of maintenance. The TF-39 engines are equipped with cowling, therefore, only the sides, front, and rear of the jet car require the cover panels.

An external control panel provides the operator with the controls to start the engines, control engine speed, and release the car. See Figures 69, 70, and 71. The panel also provides the operator with a display of the gages required to monitor engine performance in addition to gages identical to those provided on the jet car. The control panel is connected electrically to the jet car through the quick-disconnect fitting.

### 3. DEADLOAD CONCEPTUAL DESIGN

a. The basic concept of a steel frame dolly suspended on aircraft wheels was utilized in the design considerations of this study. The weight of the dead-

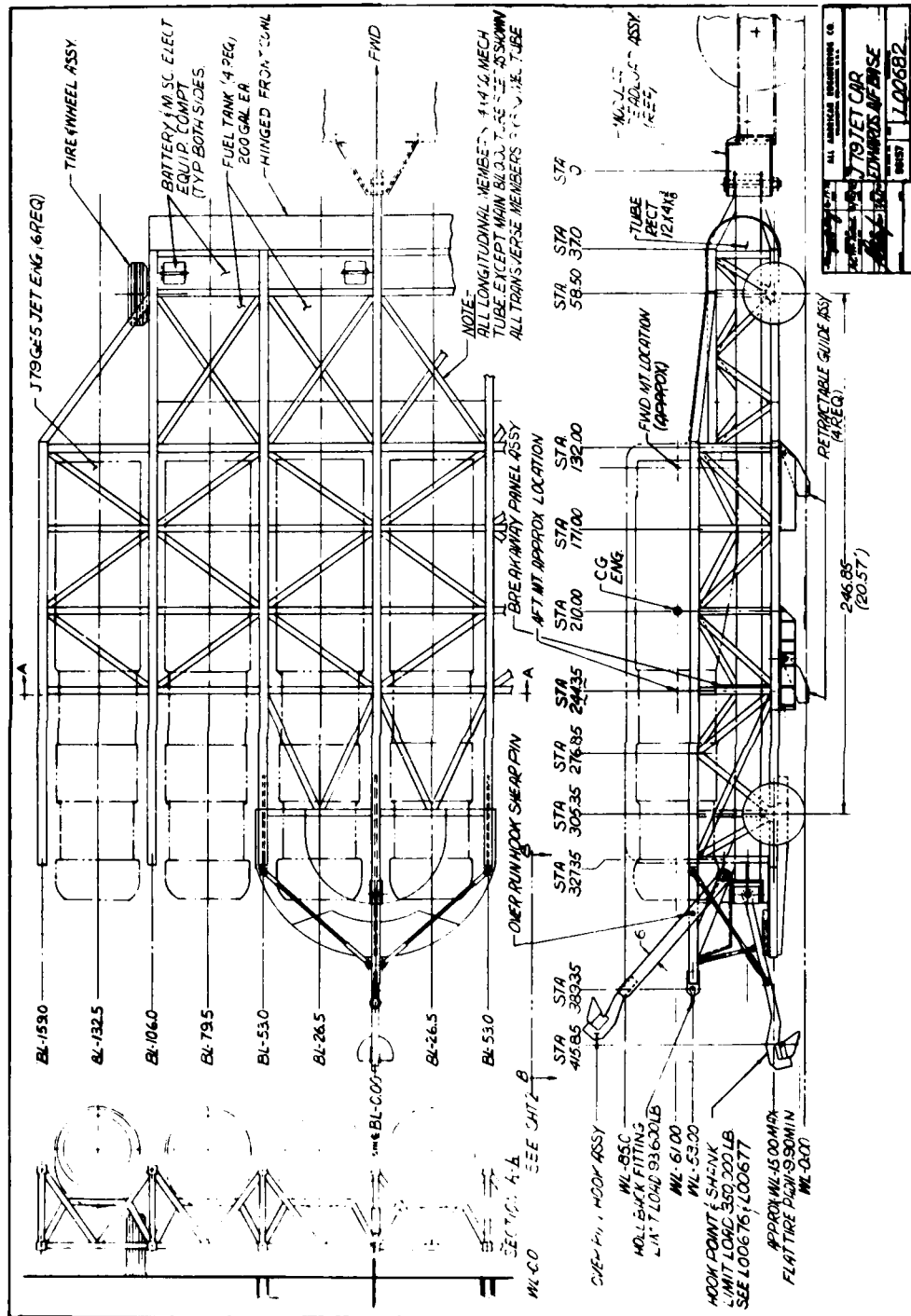
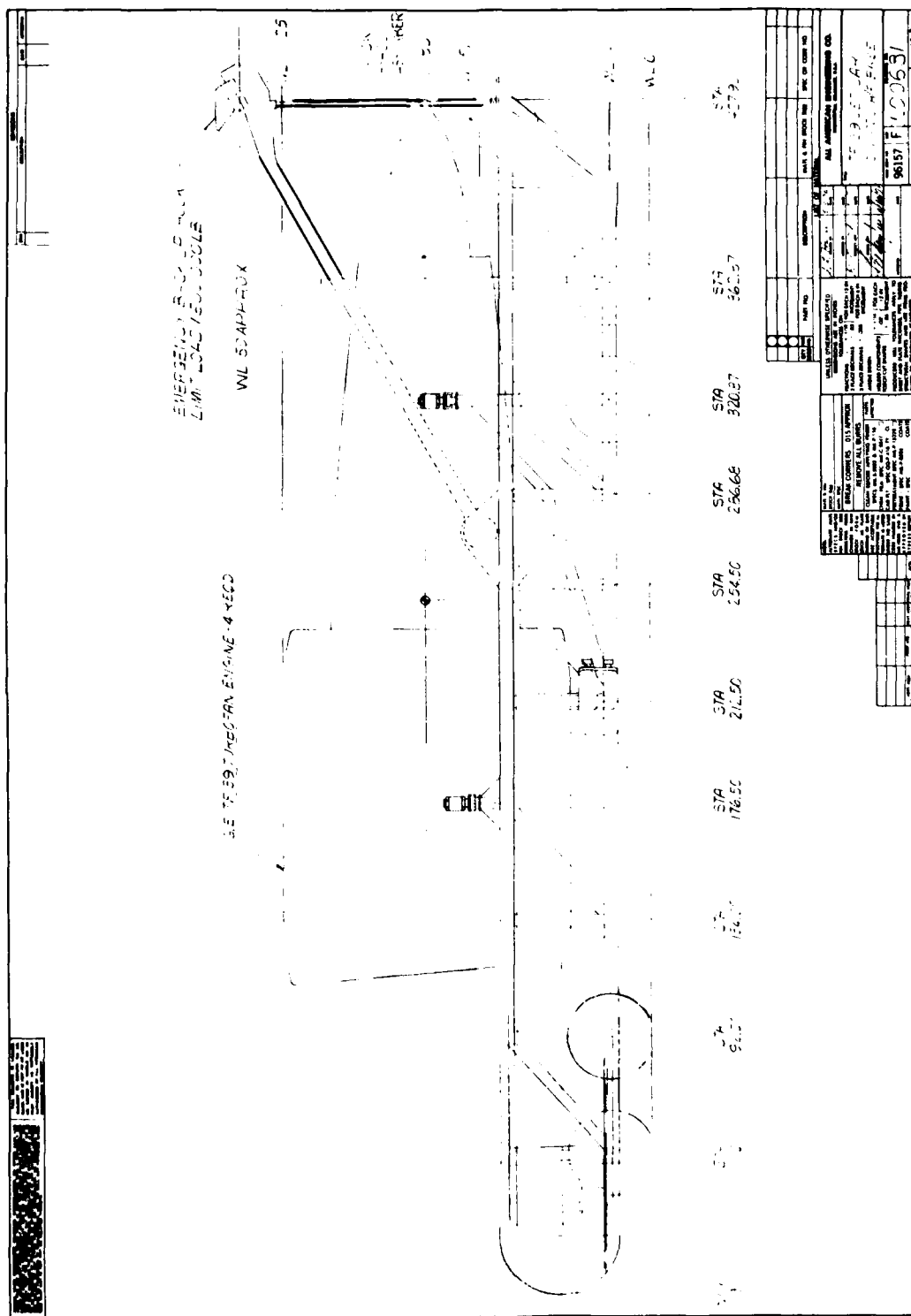
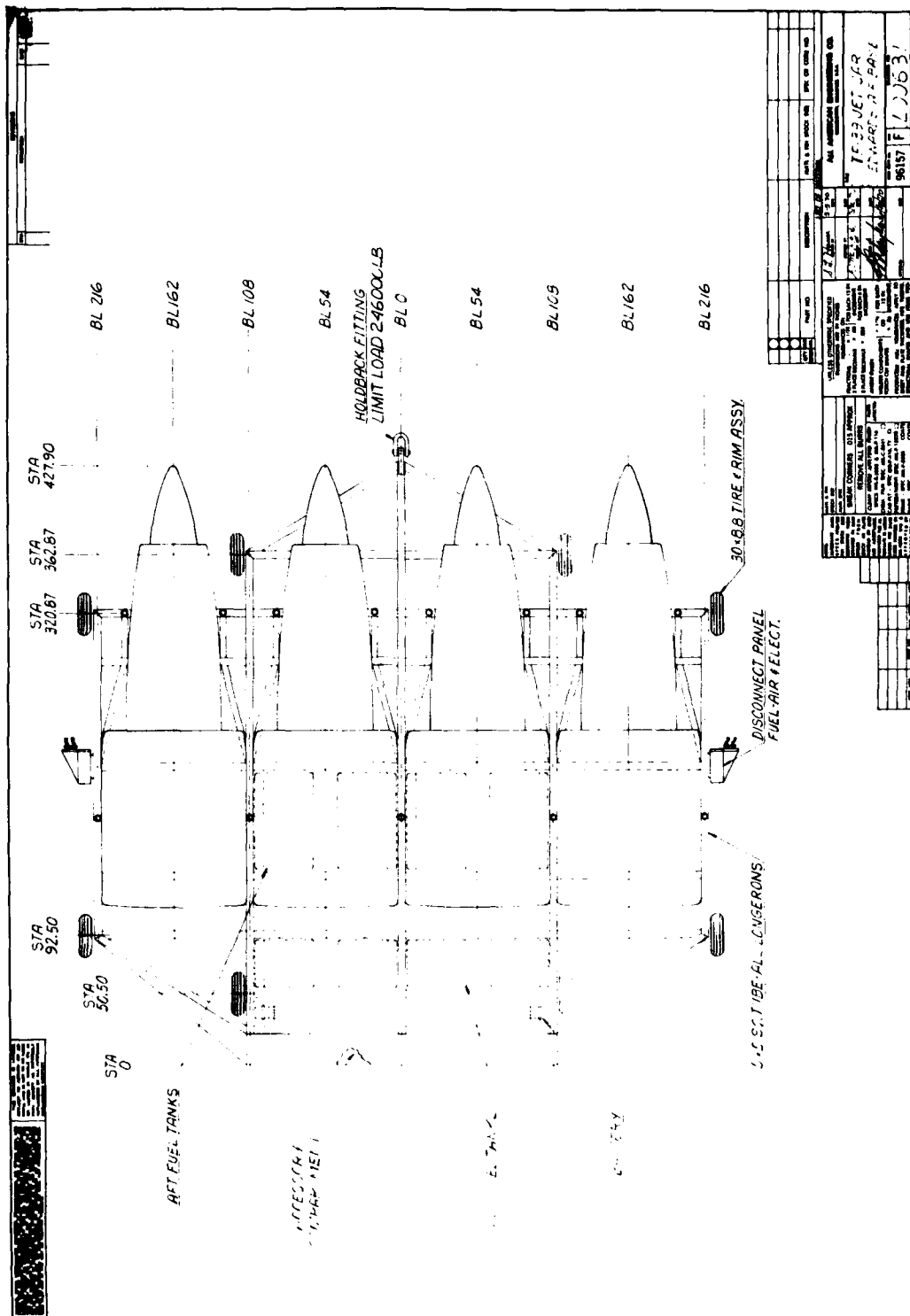


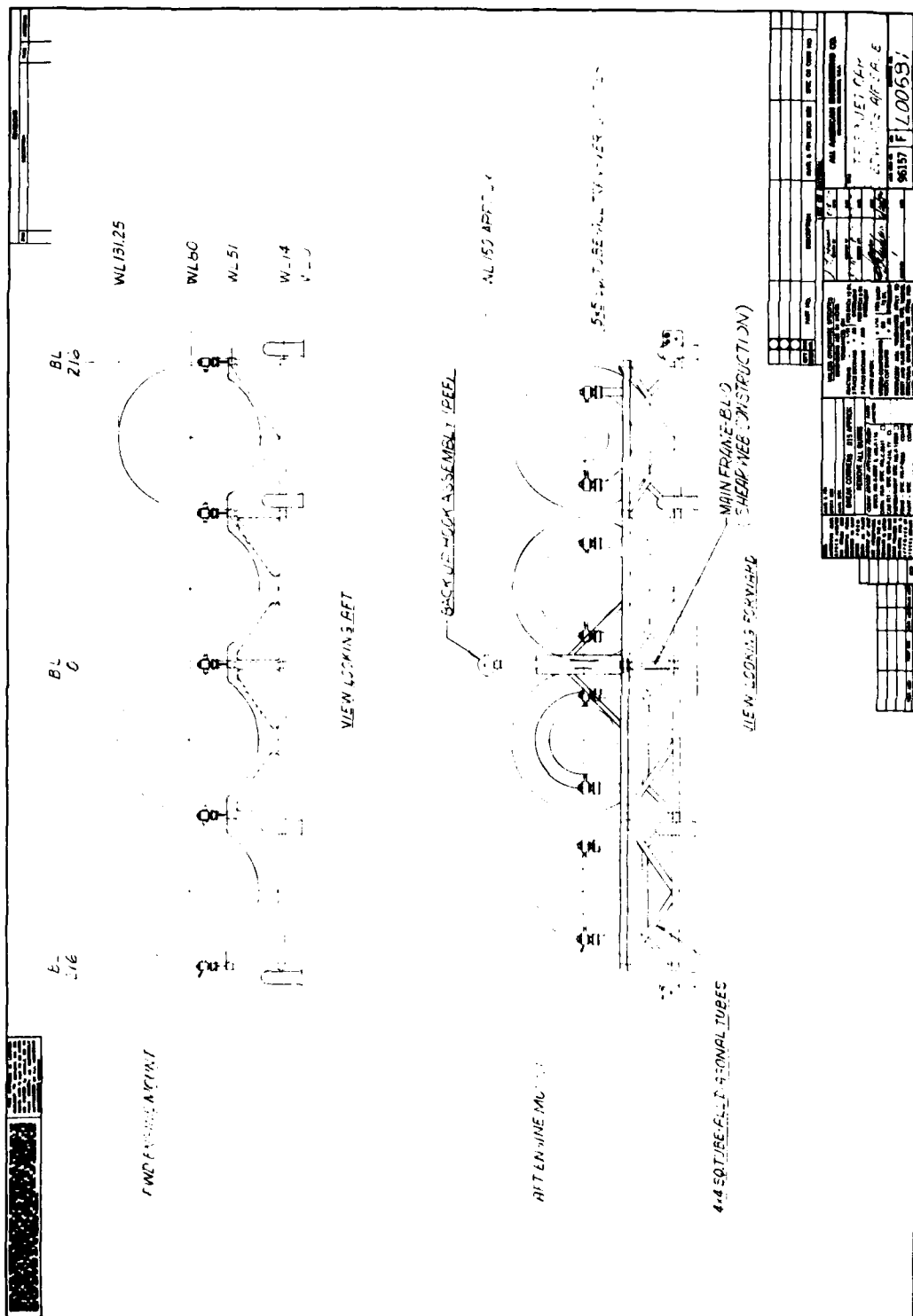
Figure 67. J-79 Jet Car







"Figure 68 ----Continued"



"Figure 68---Concluded"



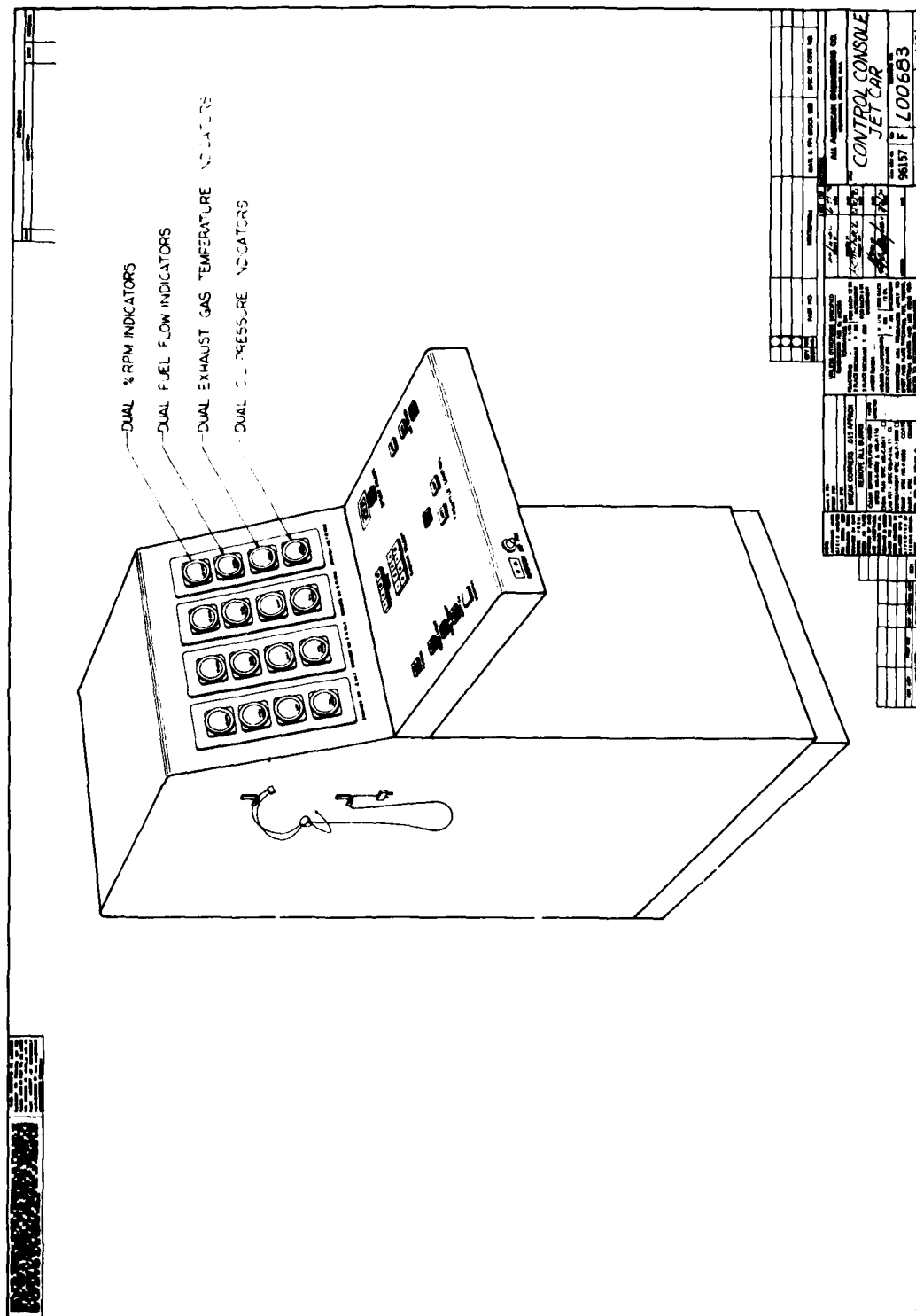
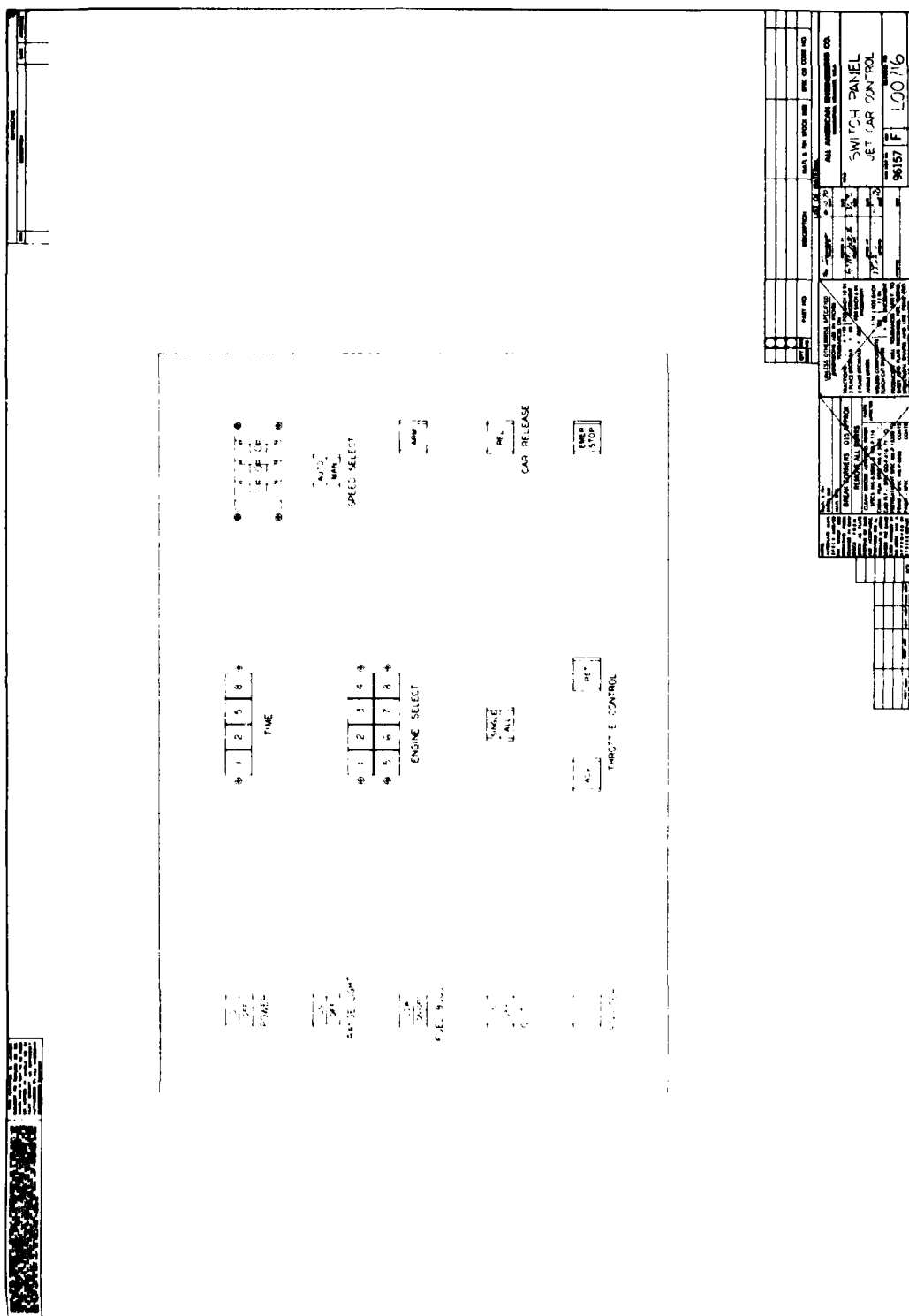


Figure 69. Jet Car Control Console





**Figure 71. Switch Panel - Jet Car Control**

load is varied by the addition or removal of sized weights to reach the desired configuration to be tested.

b. Choice of Weight Materials

(1) Concrete

As stated above, the weight of the deadload is varied by the addition or removal of sized weights. These weights are 2500 pounds each and constructed of channel, reinforcing bar, and concrete. See Figure 72. This size weight requires approximately 18 cubic feet of concrete at a cost of \$1.10 per cubic foot. Allowing approximately \$30.00 for the cost of channel and re-bar brings the total cost of the concrete weight to \$50.00.

(2) Steel Weights

The weights could be made of steel plate, however, the cost is considerably higher than concrete. The cost of steel is approximately ten and one-half cents per pound. At an average weight of 2500 pounds the cost of the weight is \$253.00. Consequently, the cost of steel weights is five times greater than those made of concrete. The physical size of the deadload utilizing steel weights, however, is 30 percent less than that utilizing concrete.

(3) Water Ballast

Another method of varying the weight of the deadload considered was water ballast. For this purpose a deadload design was considered as shown in Figure 73. This is basically an oversized tank car. The construction is of the single unit type utilizing steel "I" beams and plate. Baffle plates are provided inside the tank to reduce the shifting of weight due to sloshing of the liquid. This method was eliminated from further consideration as impractical and costly. The air drag on the frontal area of the deadload would reduce the efficiency of the propulsion system. It is anticipated that sloshing at less than full-up configuration would cause some affect on arresting gear performance due to weight shift.

(4) Recommended Material

It is recommended that the deadload weights be constructed of concrete. While it is true the relative size of the deadload can be reduced by utilization of steel weights it is felt that this could not offset the cost savings realized with concrete weights. The overall cost differential for the 750,000 pound deadload would be \$52,000.00 if steel material was used instead of concrete.

c. Designs Considered

For purposes of this study several design concepts for deadloads were considered. Based on overall requirements and cost factors, four were considered acceptable and carried into the preliminary design stage.

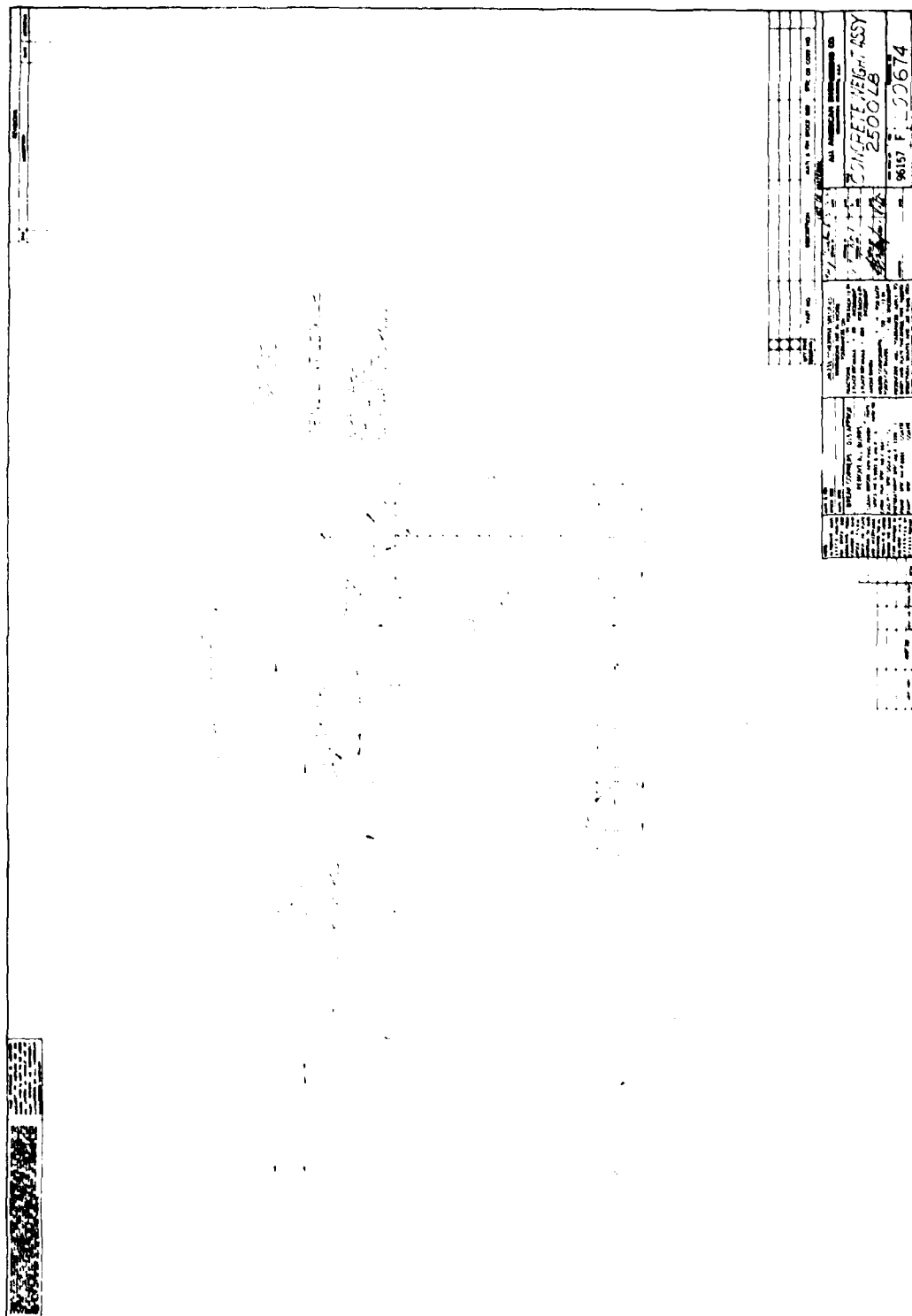


Figure 72. Weight Layout

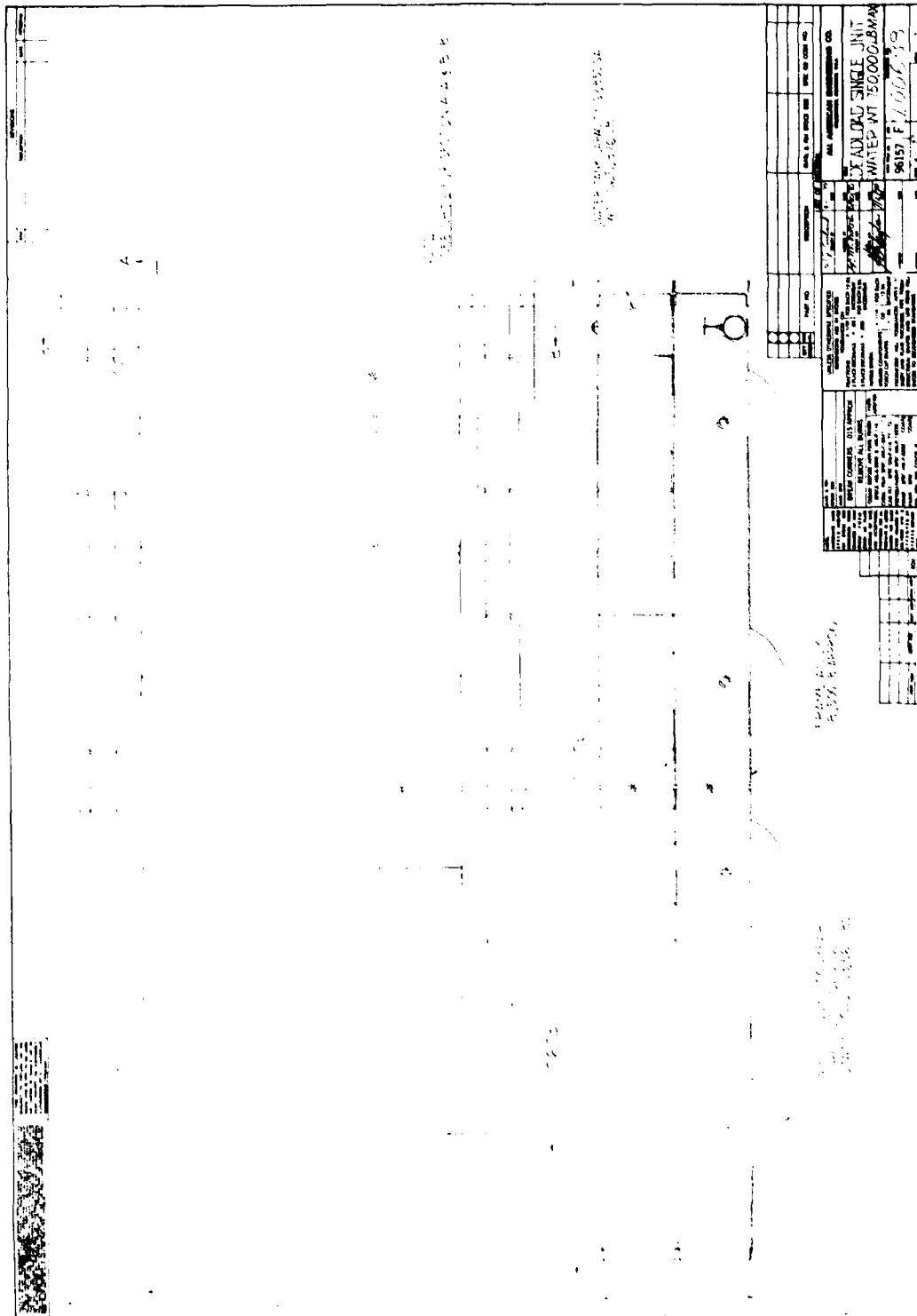


Figure 73. Dead Load Single Unit - Water Ballast



(1) 40,000 to 175,000 pound deadload.

This deadload is a single unit frame suspended on six wheels as shown in Figure 65. It utilizes 54 concrete weights to vary the weight from 40,000 pounds to 175,000 pounds. The size of 20 feet  $\times$  30 feet is within reasonable limits for handling and operations. The minimum weight which can be obtained in conjunction with a proposed J79-5 engine jet car is 70,000 pounds and the maximum is 210,000 pounds. This is based on utilizing the jet car pushing and as part of the deadload configuration.

(2) 100,000 to 750,000 pound Deadload

This deadload is a single unit frame suspended on fourteen wheels as shown in Figure 74. It utilizes a total of 189 weights to vary the weight from 100,000 to 750,000 pounds. The size of approximately 25.5 feet wide by 76 feet long may prove to be impractical from the standpoint of handling, both during operations and maintenance.

(3) 135,000 pound Modular Deadload

The 135,000 pound deadload is of modular construction consisting of three basic modules, each one suspended on four wheels. This concept is shown in Figure 75. A total of 48 weights, sixteen in each module, are utilized to vary the weight as well as adding or removing modular sections.

The weight range of the deadload as designed is 8,500 to 135,000 pounds. This is accomplished by constructing the deadload in modular sections which can be added or removed as required. The basic module is a four-wheeled dolly with a weight range of 8,500 to 45,000 pounds. Each add-on modular section is identical to the basic module.

The deadload modules are suspended on wheels and tires of the size and load rating utilized on the B-52 aircraft. They are unsprung, and non-steerable and shaft mounted as shown in Figure 77. At the maximum weight condition of the basic module of 45,000 pounds each of the four wheels is supporting 11,250 pounds. This is well below the maximum allowable wheel load of 76,000 pounds for this size wheel and tire.

(4) 125,000 pound Modular Deadload

The 125,000 pound deadload is of similar modular construction; this concept is shown in Figure 76. The first module is suspended on four wheels whereas the other three modules are supported by two wheels. The four wheeled module has a basic, empty weight of 7,500 pounds which may be increased to 32,500 pounds by the addition of suitable ballast. The two wheeled modules can have a weight variation of 5,500 pounds empty to 30,500 pounds each when fully loaded.



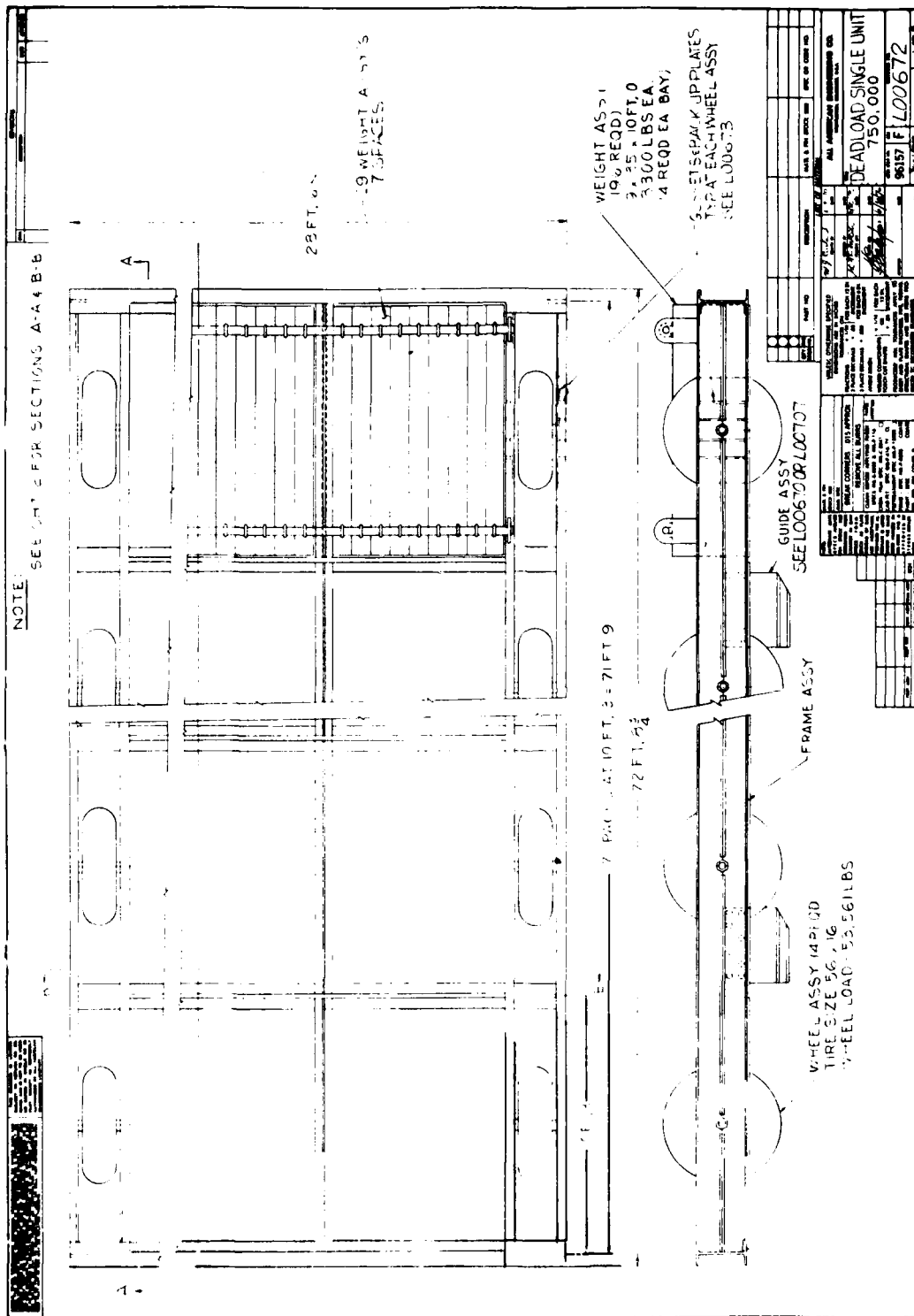
(5) 681,600 pound Modular Deadload

The 681,600 pound deadload is also of the modular construction. It consists of four modular sections each having a weight range of 30,400 to 170,400 pounds. Each module is suspended on four wheels and tires of the size and load rating of the B-52 aircraft. See Figure 78.

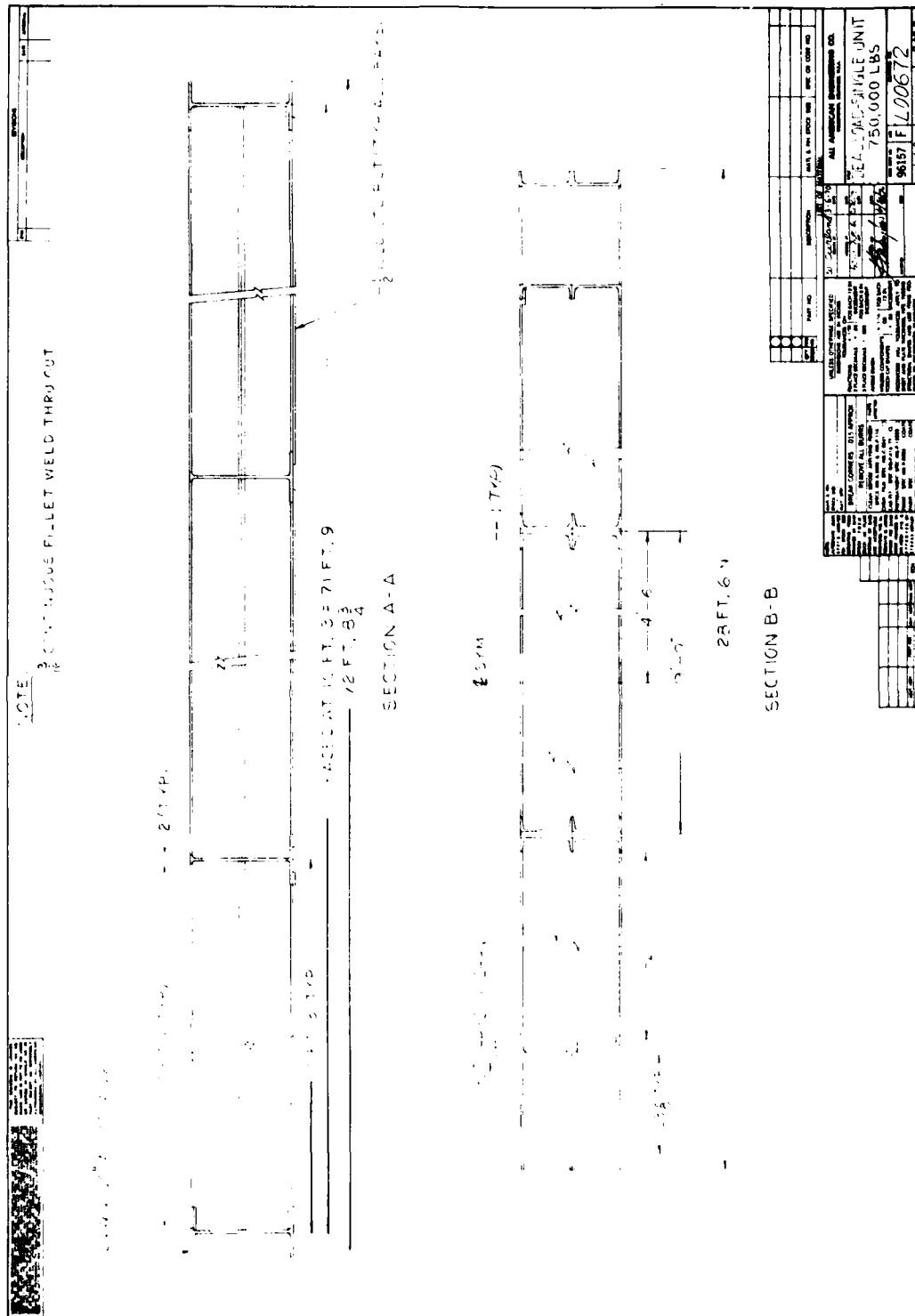
The weight range of this proposed deadload is 30,400 to 681,600 pounds. This is accomplished by adding or removing concrete weights in each module as well as adding or removing modules. A total of 58 concrete weights are utilized to vary the weight of each module. A nominal test weight of 750,000 pounds is obtained by loading this deadload to its maximum and adding to it the 75,000 pound weight of the TF-39 jet car which are both engaged and arrested as a unit test vehicle.

(6) Recommended Choice of Deadloads

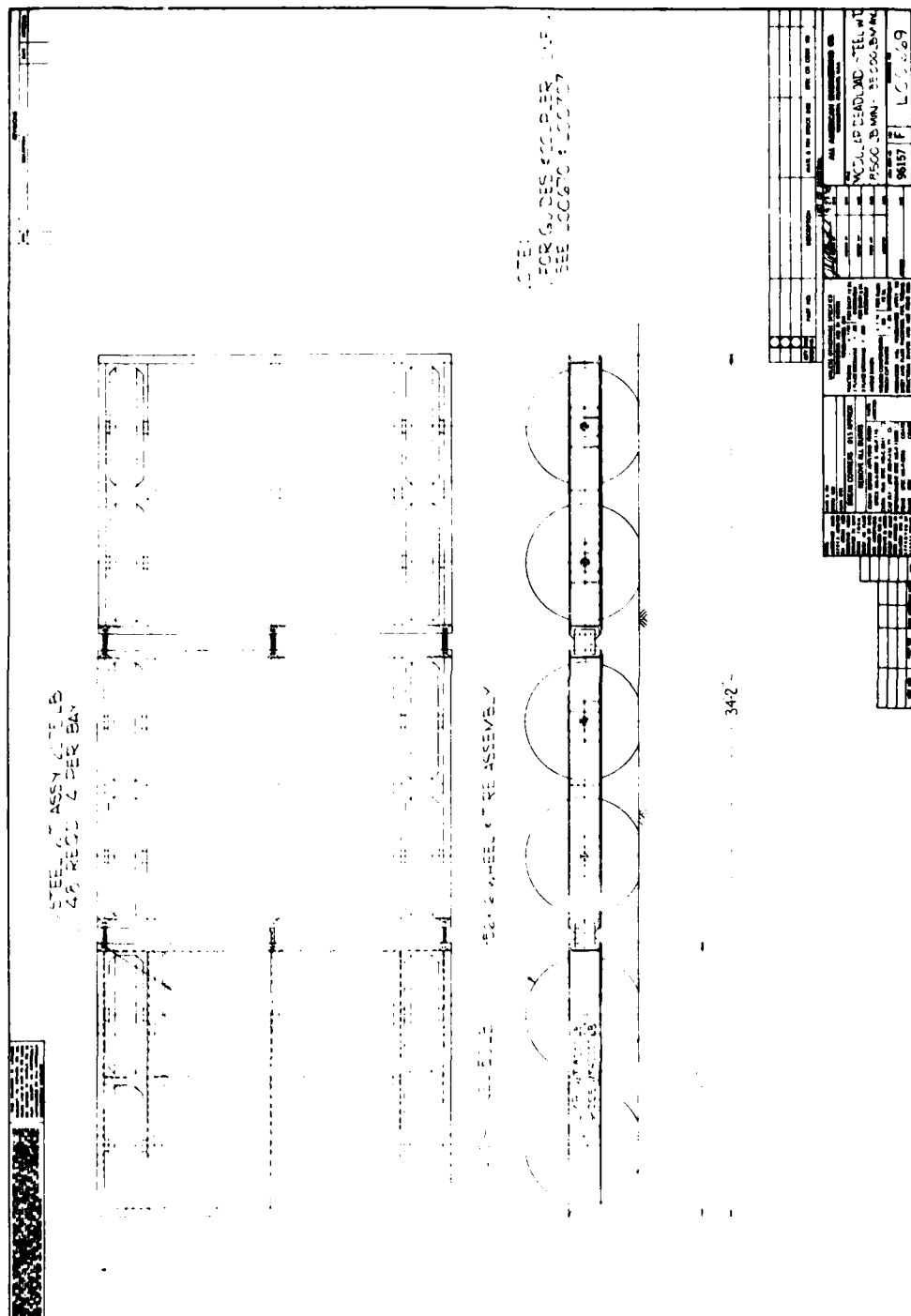
The recommended choice of deadloads is that choice which will allow the AFFTC the flexibility of varying the weight of vehicles to be tested with the minimum dollar expenditure for hardware. This choice is shown in Figures 79 and 80. These two figures show that the complete range of weight requirements can be accomplished by utilizing one 45,000 pound deadload module and a total of four larger deadload modules which, when fully loaded, weigh 681,600 pounds. This 681,600 pound weight would be increased by 75,000 pounds, the weight of the TF-39 jet car when required. It is possible that some further economy may be realized by building the jet car frame to allow the installation of either J-79 or TF-39 engines as required.



**Figure 74. Dead Load Single Unit - 750,000 Lbs.**



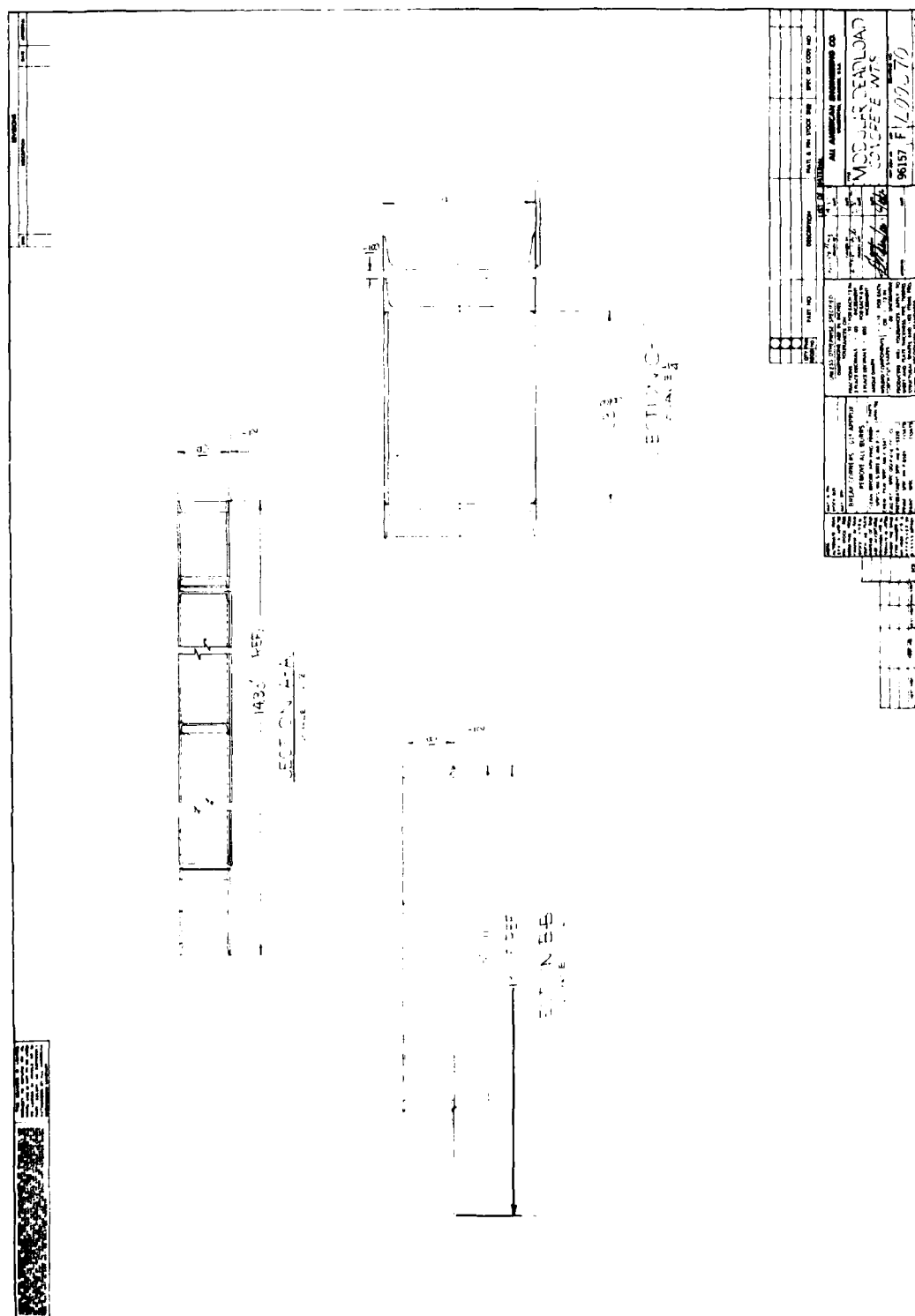
"Figure 74---Concluded"

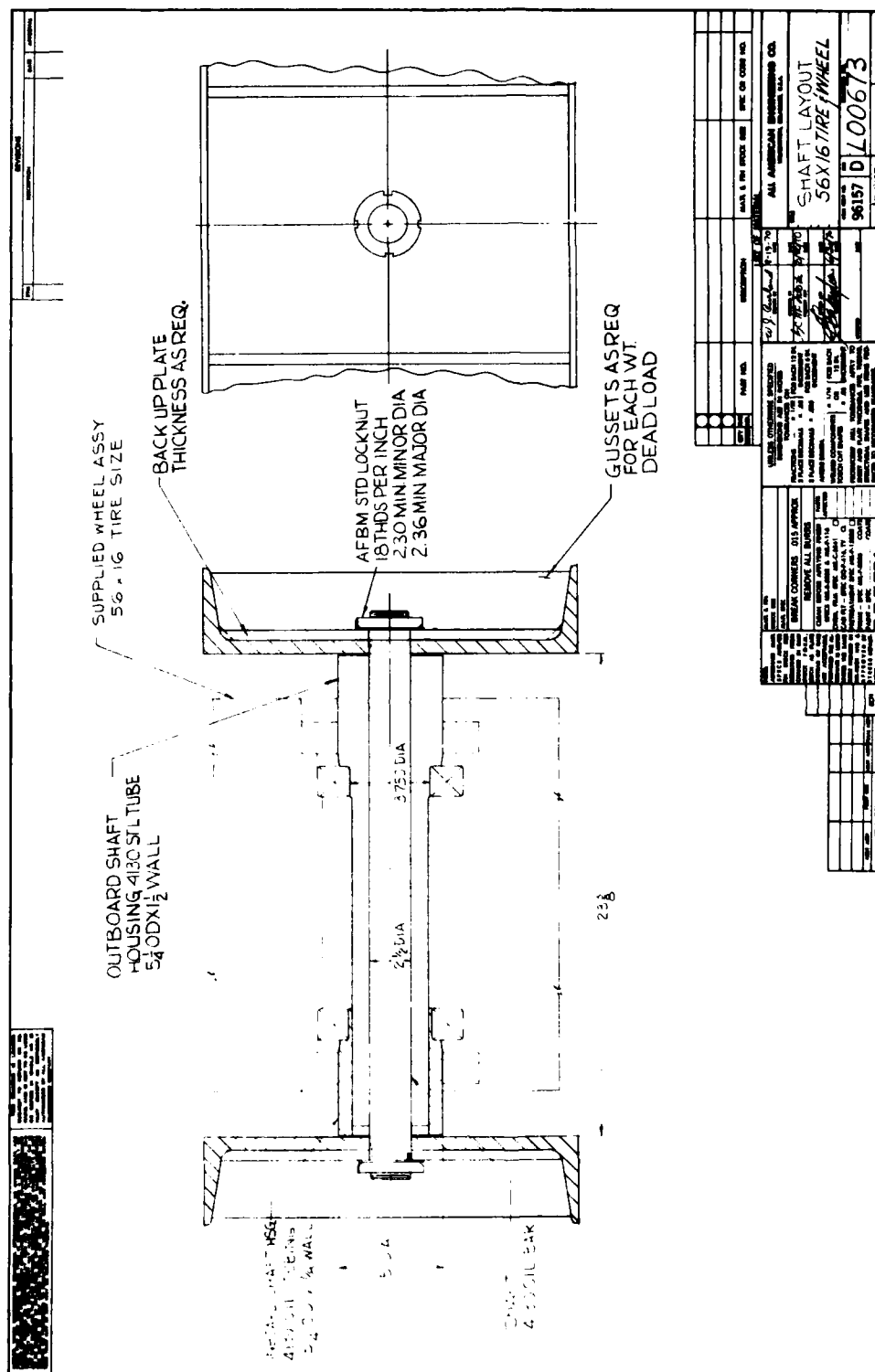


**Figure 75. Modular Load - Steel Weight 8500 - 135,000 Lbs.**















WEIGHT RANGE

8,500 - 45,000



T-38, F-5, F-102, F-104, F-100, F-106, A-7D

OR

45,000



A-7D

Figure 79. 45,000 Modular Dead Load and J-79 Jet Car Arrangement

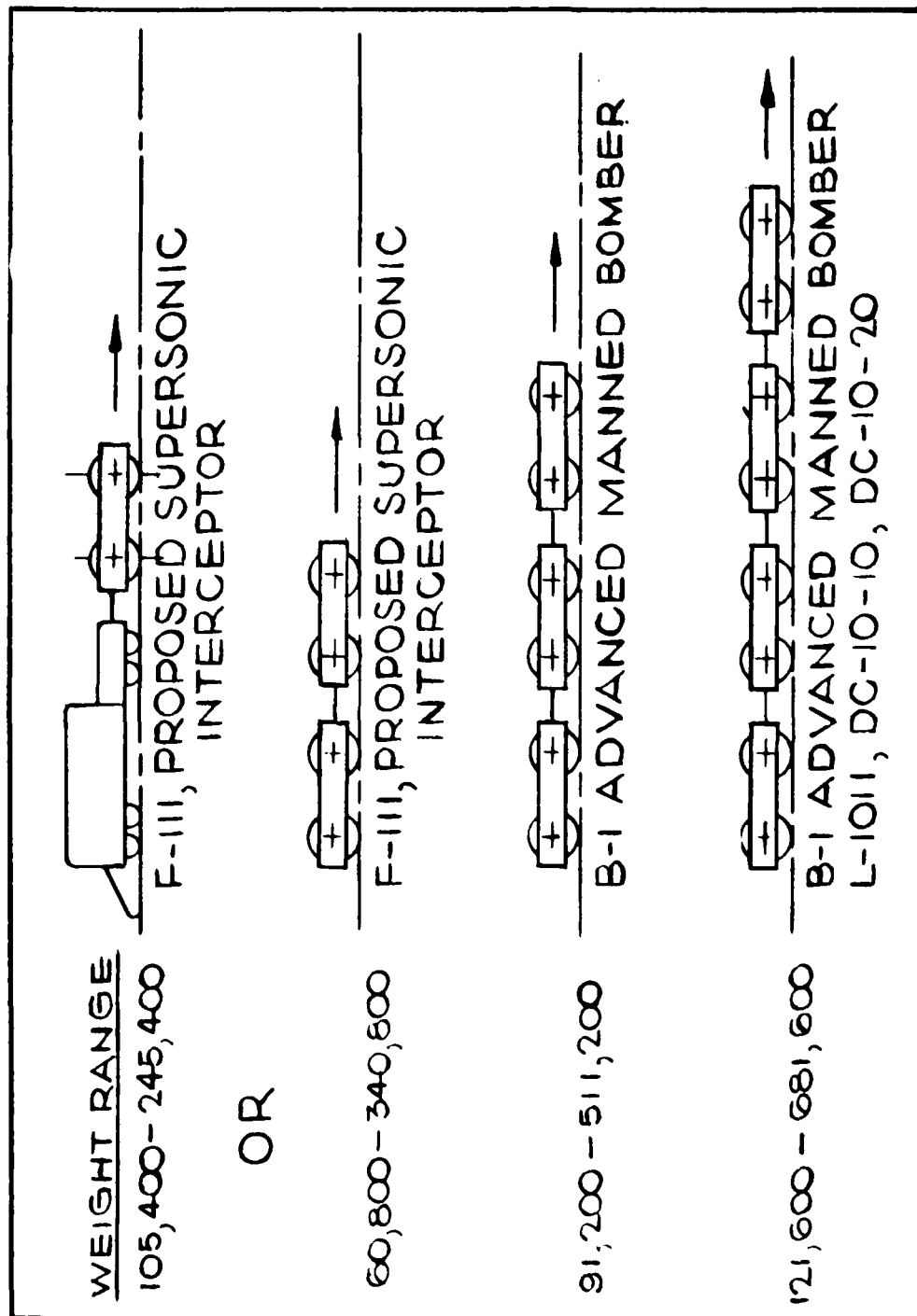
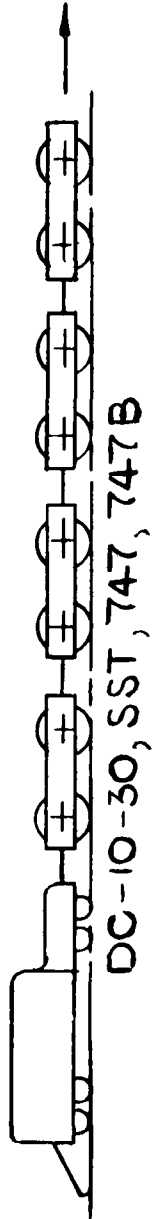


Figure 80. 681,600 Modular Dead Load and TF-39 Jet Car Arrangement

WEIGHT RANGE - 196, 600 - 756, 600



## SECTION X

### CONCEPTUAL DESIGN OF THE REQUIRED FACILITY

#### 1. EVALUATION OF PROPOSED KEEL STRIP

It is the contractor's understanding that the basic proposed expansion of the facility as originally conceived was the addition of a thickened center strip of the runway which would be required to support aircraft or deadload vehicles which would weigh up to 728,000 pounds. The new strip, called a "Keel Strip" as designed is 18 inches thick and 50 feet wide. Although not a contractually required part of the study effort, it was decided to evaluate the basic design of the keel strip.

##### a. Subgrade Evaluation<sup>(1)</sup>

The existing runway is reputed to have been originally constructed of virgin subgrade consisting of a dry lake bed known as "Rogers Dry Lake" and without the use of sub-base ballast course. A proper assessment of the supporting value of the subgrade in question would normally require determining its modulus of reaction (designated as "K"). This is usually obtained by performing plate-bearing tests on the subgrade or loading an existing pavement on the same subgrade and correlating the results with soils of known "K" value. A similar correlation with California Bearing Ratio (CBR) for the subgrade could also yield similar results. However, since these tests are outside the scope of the subject contract, the subgrade evaluation will be based on conservative assumptions using soil characteristics normally associated with lake beds in general and the related geographical area.

Lake bed (lacustrine) deposits are generally very fine in regards to size of particles and consist of silts and clays because of the low velocity with which water flows through most lakes. In addition, agricultural soil maps identify the area under evaluation as a Loess deposit belt formed by dust and loose sand grains carried westward from the Great Plains. The finer wind-blown soil deposits of silt size (smaller than 0.05 mm) eventually become eroded and re-deposited in lake beds by rain water. Based on the above, it appears feasible to assume that the subgrade in question could easily have a fine sand, silt and clay consistency and be high compressible when saturated since the combined action of water flowing into the lake and of wind blowing over it during the dry seasons

<sup>(1)</sup> Soil Mechanics, Foundations, and Earth Structures by Gregory P. Tschebotarioff, Chapter 2, 1st Edition, McGraw-Hill Book Co., Inc.

generally produces an unusually loose clay structure. The clay becomes over-consolidated by repeated drying processes and is highly compressible when re-saturated.

A comparison of these assumptions with Figure 81 showing the interrelationships of soil classifications, California Bearing Ratios, bearing values and "K" values; would place this soil consistency in the "very poor subgrade" classification with a CBR ranging from 2 to 5. Since the sub-grade in question presently appears to be feasible to some degree of utility, a CBR value of 3 and subsequent "K" modulus of 100 has been assumed as adequate for the subject assessment.

#### b. Assessment of Pavement Thickness

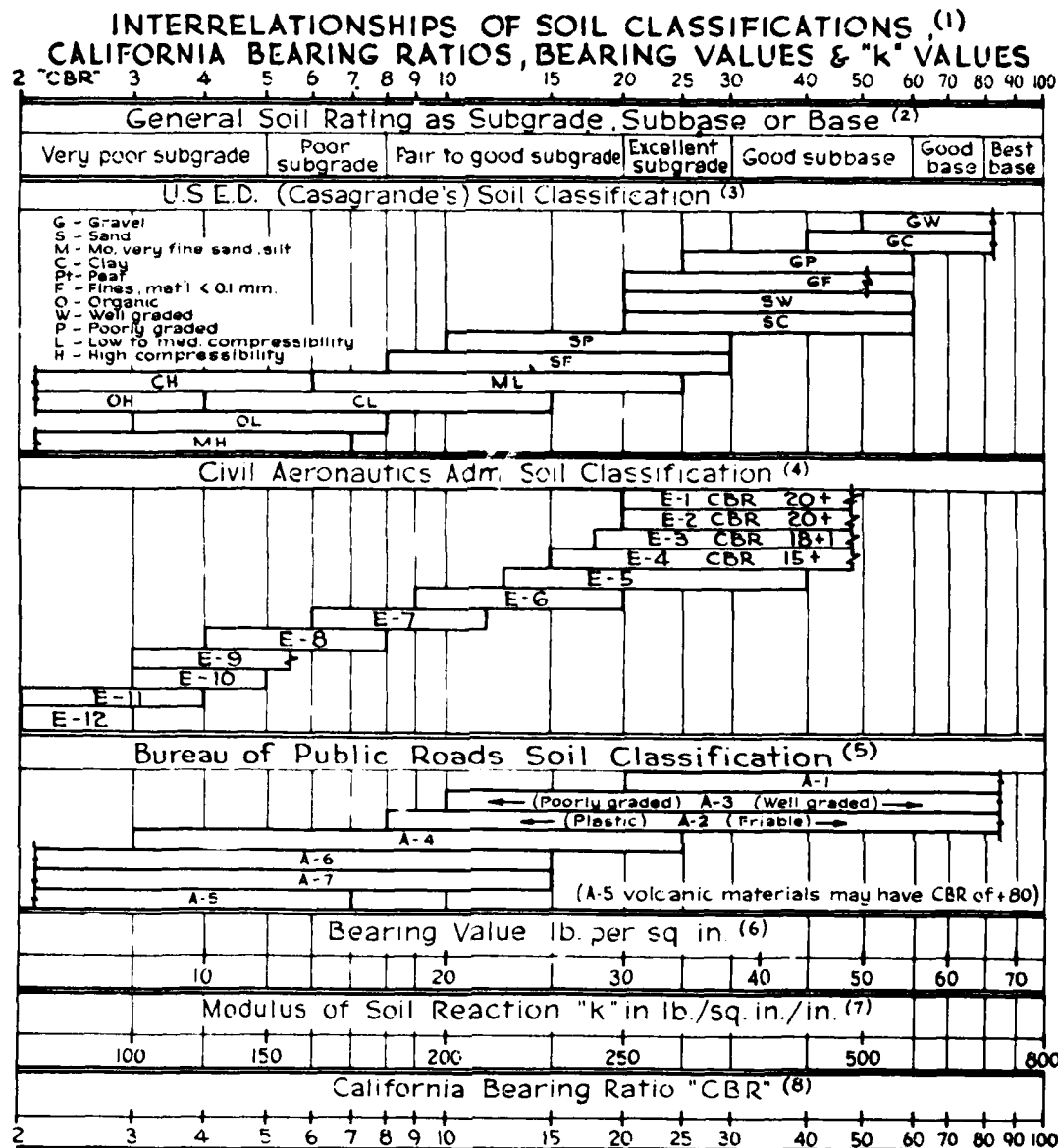
The next assumption to be considered concerns the physical properties of the concrete. These properties, which may affect the load-carrying capacity, are the modulus of elasticity,  $E$ , Poisson's Ratio,  $\mu$ , and the modulus of rupture or flexural strength. However, since variations in  $E$  and  $\mu$  have little effect upon stress in a pavement, the following assessment is based on the average values of  $E = 4,000,000$  psi,  $\mu = 0.15$ , and a modulus of rupture of 600 psi at 28 days.

This assessment is based on the use of influence charts developed by the Portland Cement Association, using the basic equations of Dr. H. M. Westergaard<sup>(2)</sup>. The pavement thickness read from these design charts is the thickness of a slab having a uniform cross-section. The influence chart from which these design charts were developed was based on the assumption that the load is applied at some distance from any edge of a large slab. It is, therefore, evident that any thickness obtained from the design charts is theoretically correct when a load is located in the interior of a slab. When the slab edges at all joints (longitudinal and transverse) are provided with adequate load transfer, it has been found that a paved area acts as a continuous large slab. This is substantiated by the performance of existing airport pavements and by observations made on full-scale experimental slabs.

A safety factor of 2.0 has been applied to the modulus of rupture or flexural strength of the concrete as recommended in the aforementioned reference to obtain a pavement adequate for an unlimited number of operations at any one point.

Applying the above parameters to Figure 82 results in requirement for 15-1 2 inches of concrete to sustain a desired single wheel load of 50,000 pounds at a tire pressure of 240 psi. It appears reasonable to assume, therefore, that the intended 18-inch thickness is adequate based on this deadload wheel load.

<sup>(2)</sup> Design of Concrete Airport Pavement, Portland Cement Association.

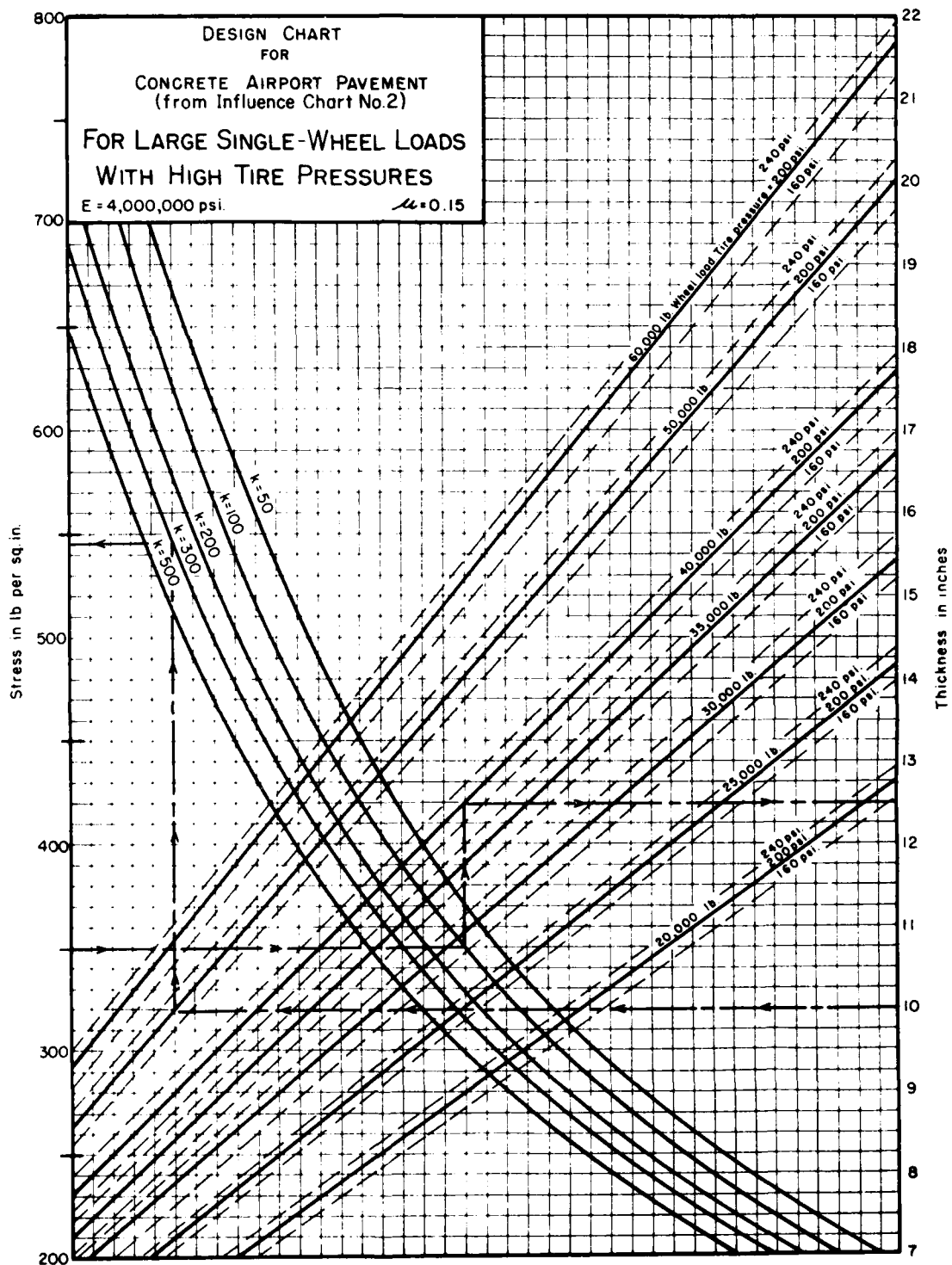


- (1) All interrelationships are very approximate. Actual tests are required to determine "CBR", "k", etc.  
(2) See "Foundations for Flexible Pavements" by O.J. Porter, 22nd Annual Meeting, Highway Research Board 1942 for basic idea.  
(3) Relationships from Engineering Manual, Chapter XX, March 1943, War Department, Office of Chief of Engineers. See also, "Soil Tests for Design of Runway Pavements" by Middlebrooks & Bertram, 22nd An Mtg H R B 1942.  
(4) CBR values estimated from old CAA classification system.  
(5) See item (3). A-6 and A-7 soils cut off at CBR-15, rather than 25 as indicated in Chapter XX.  
(6) See second reference of item (3), page 184. Bearing values at 0.1 in. deflection, bearing area not given.  
(7) See item (3). "k" is factor used in Westergaard's Analysis for thickness of portland cement concrete pavement.  
(8) See items (2) and (3).

\*Reprinted from "Design of Concrete Airport Pavement"  
by All American Engineering Company by permission  
of Portland Cement Association, copyrighted 1946.

Figure 81. Interrelationships of Soil Classifications





\*Reprinted from "Design of Concrete Airport Pavement,"  
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**Figure 82. Design Chart for Concrete Pavement**

This analysis does not consider the proposed 475 psi tire pressure loading of the thickened section of concrete.

In regards to placing the concrete on a virgin subgrade, the aforementioned reference indicates that research on experimental pavement slabs and on concrete pavements in service has established the fact that a loaded concrete pavement imposes very low unit pressures on the subgrade. For this reason, it is unnecessary and uneconomical to build up the supporting capacity of the subgrade with thick ballast courses. These thick granular sub-bases, which are an essential part of non-rigid pavements, have no justification under concrete pavements because they add to the cost without making a corresponding addition to its capacity and serviceability.

This does not mean that sub-bases are not needed, under some conditions, under concrete pavement; but they should be used only where they will correct or counteract an unsatisfactory soil or unstable soil condition. They are needed if pavement damage from one or more of the following causes is anticipated or known to exist:

- (1) Frost action.
- (2) Swell and shrinkage in high-volume-change soil.
- (3) Pumping of fine-grained soils.

Their use for the sole purpose of increasing subgrade support (K value) in order to reduce the slab thickness is rarely, if ever, justified.

## 2. DESCRIPTION OF PROPOSED FACILITY

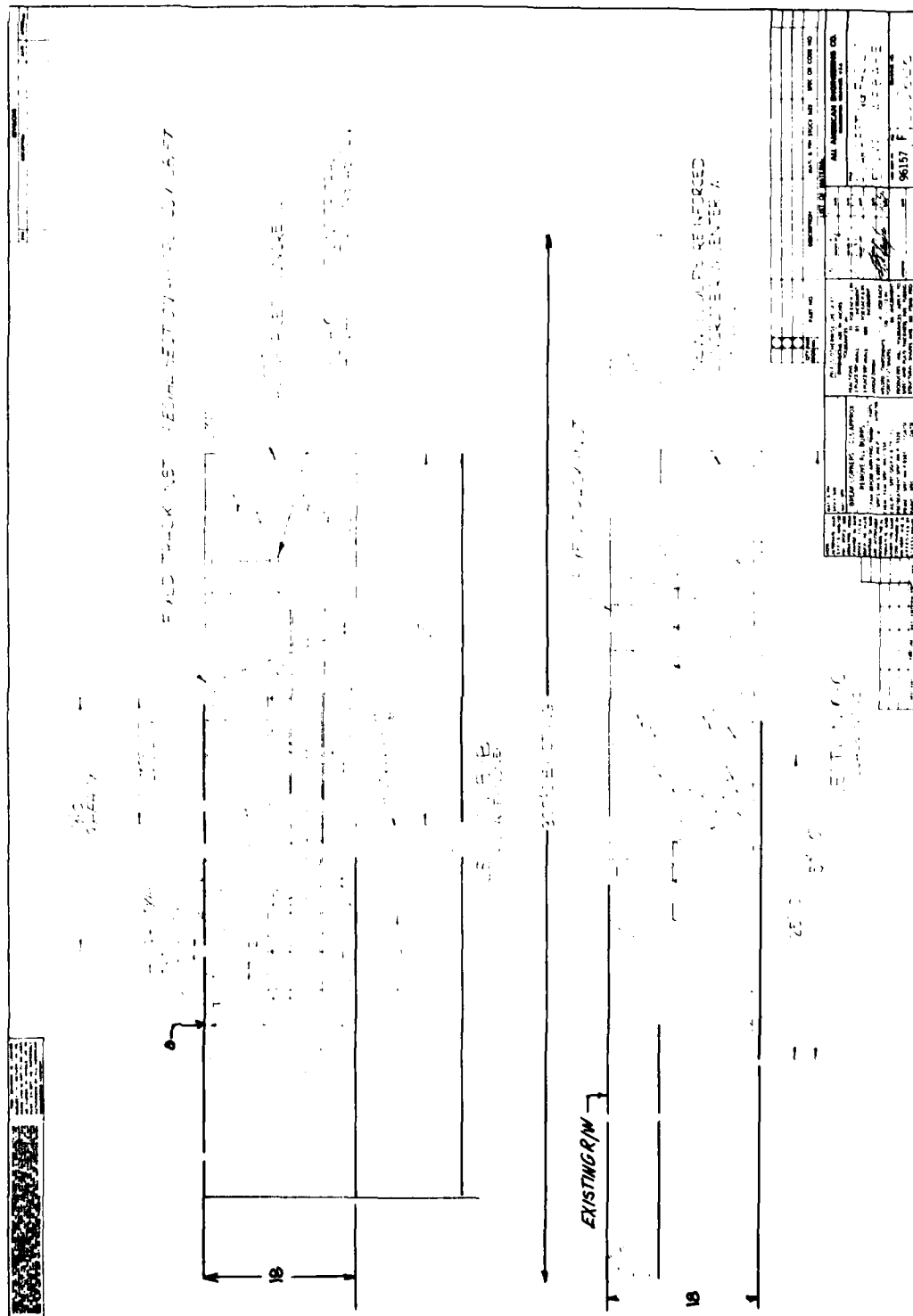
The overall layout of the proposed facility installation is shown in Figure 83. It is also shown by artist's conception in Figure 84.

A 2000 foot extension is proposed for the west end battery location of the existing runway. This 2000 foot extension is not required for the simulation of the kinetic energy required for present and proposed new aircraft for the Air Force. It will, however, be required at some future date if it is desired by the Air Force or some other governmental agencies to simulate large commercial passenger and cargo aircraft.

To facilitate operations from alternate holdback positions, the jet car control console, external fuel and power supply are trailer mounted.

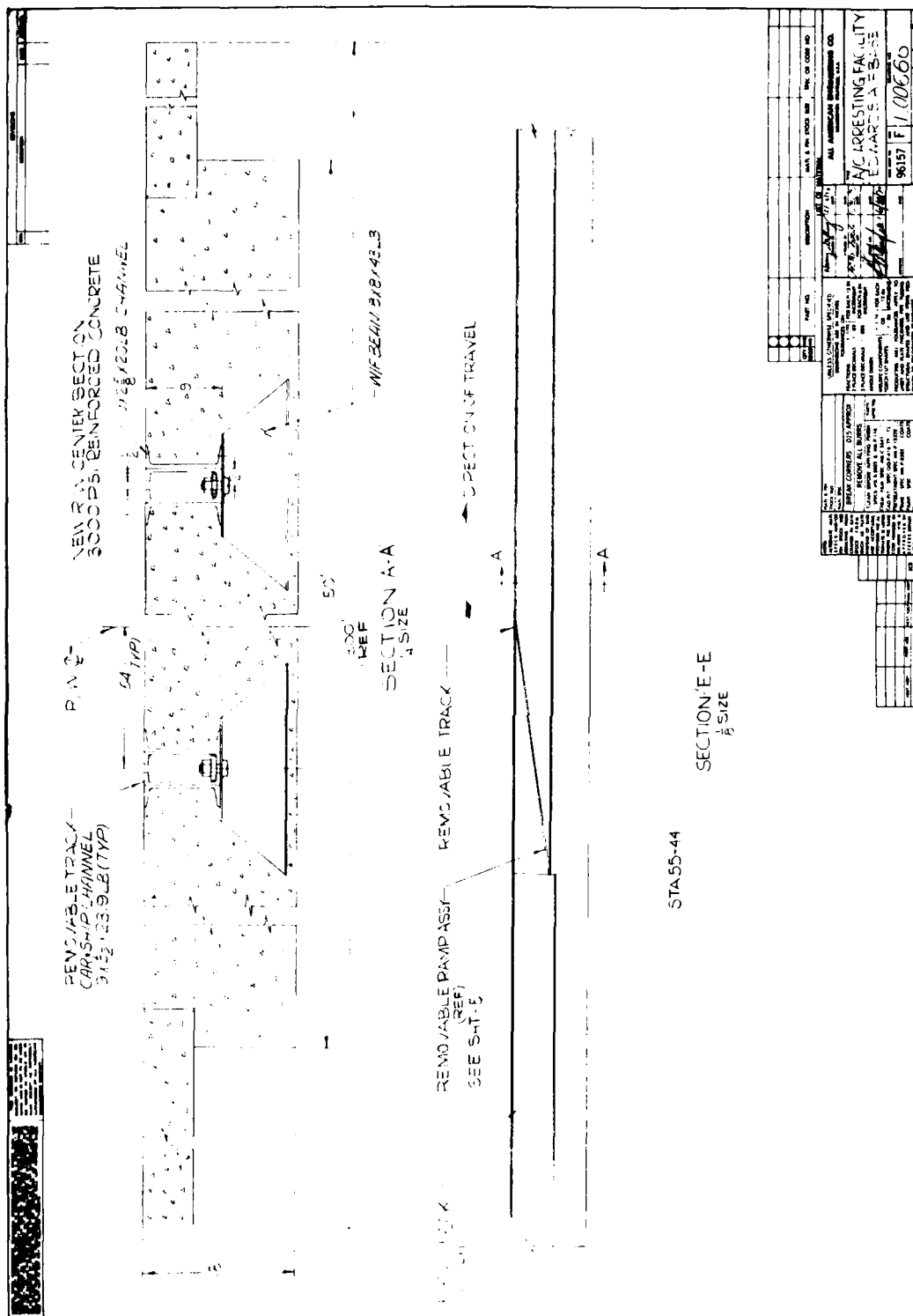
The proposed guidance system is a fixed, dual rail, flush track installation to station 55 + 44. The rail is a special "Z" shaped section with an inner bottom flange added and so designed that the upper flange provides the section modulus required to withstand the design bending loads. These rails are installed in the proposed 50 foot wide, 3000 psi reinforced concrete center strip.





"Figure 83 ---Continued"



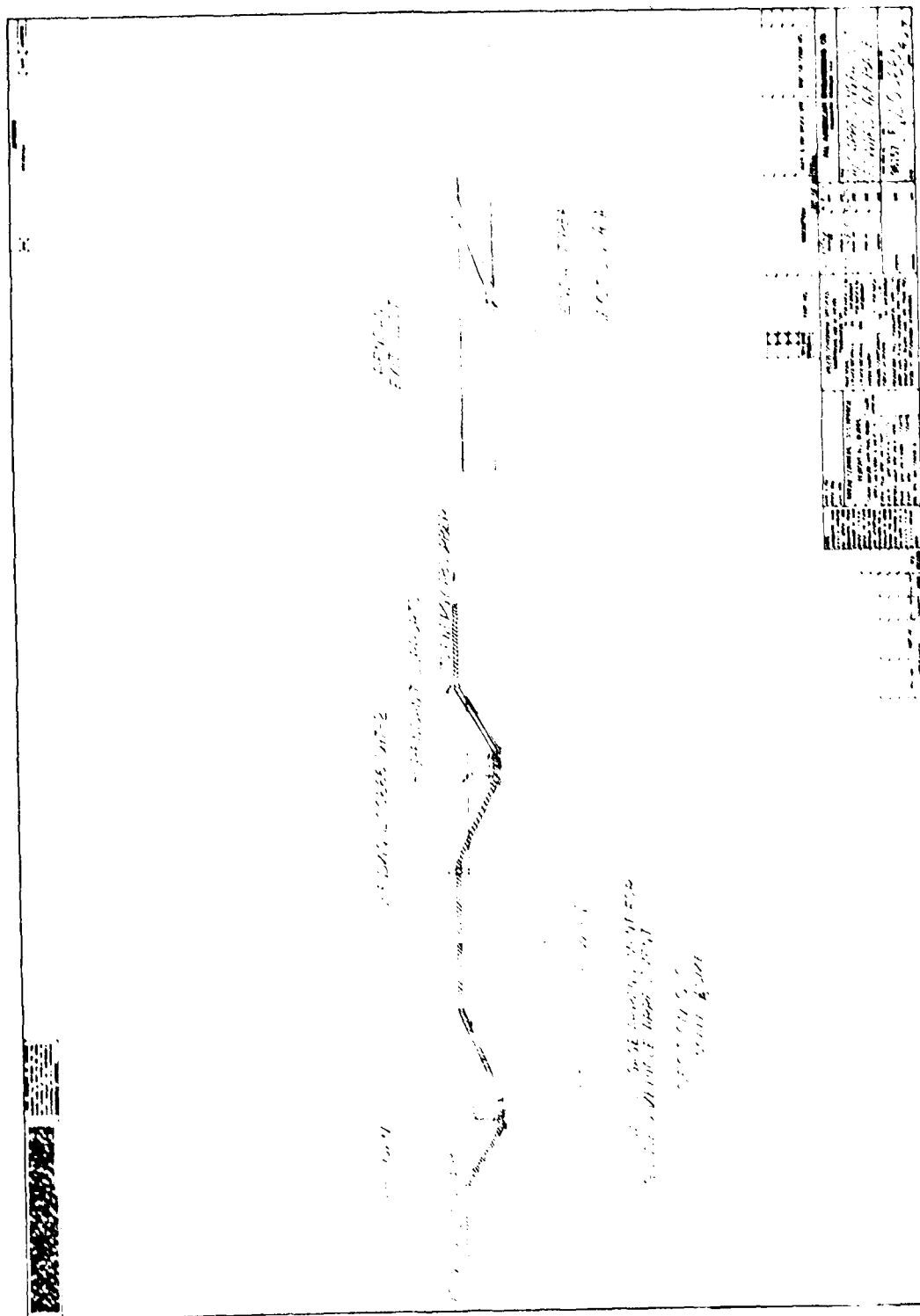


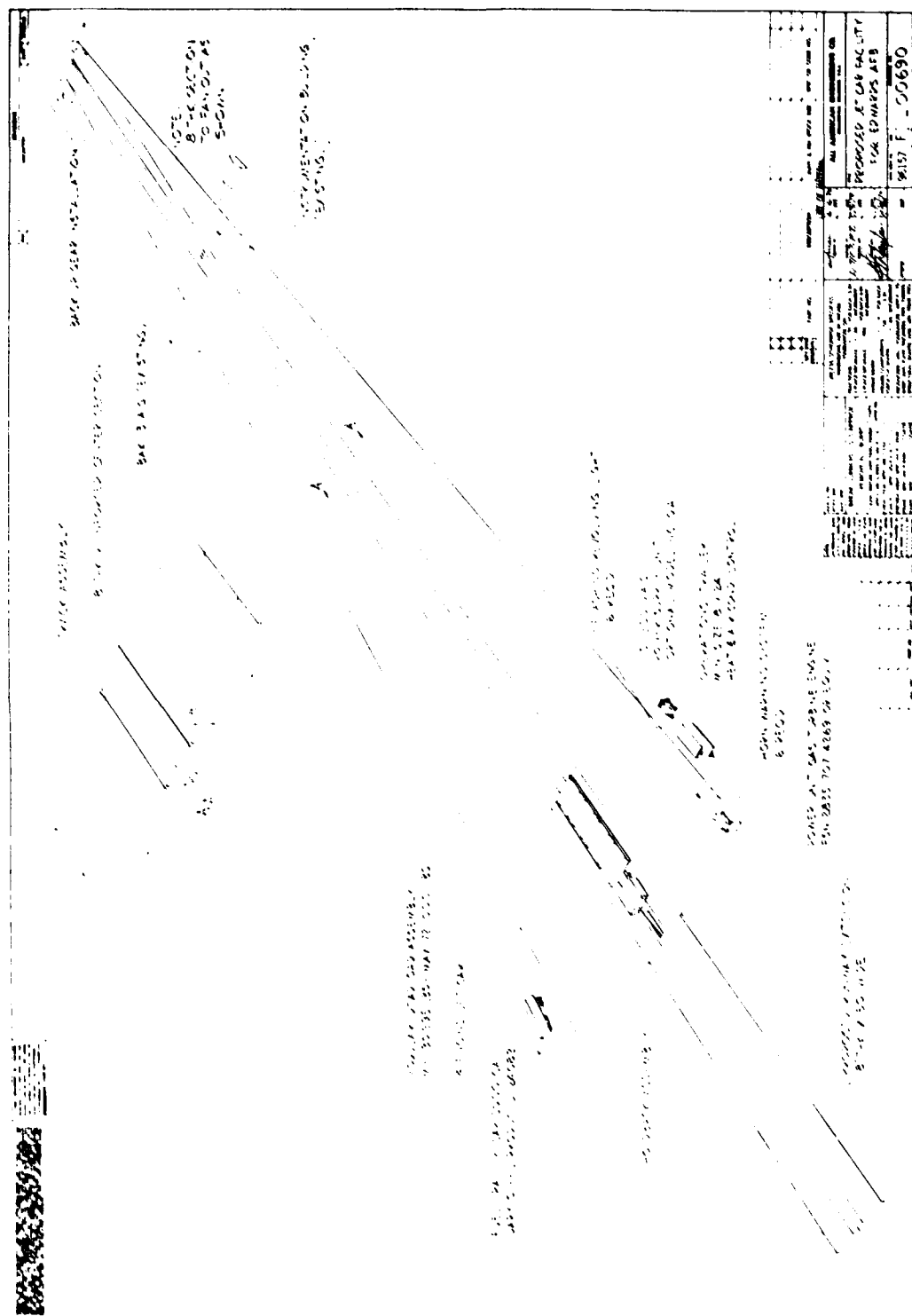
"Figure 83 ---Continued"











**Figure 84. Proposed Jet Car Facility**

The existing arresting gear pit and instrumentation building will remain intact. Some modification to the arresting gear pit must be made to allow for relocation required for off center engagements.

It is proposed that the runout area from Station 55 + 44 to Station 76 + 49.56 be modified with a fanned out section of concrete the same thickness as the keel strip section. This is to provide a runway surface area, on both sides of the centerline, which will withstand the loads imparted by the deadload wheels should it track off center in the unguided area.

An emergency back-up arresting gear is proposed at Station 76 + 49.56. It consists of an energy absorber and pendant support stanchion on each side of the runway. This provides an emergency arrestment capability in the event of a failure in the primary arresting gear or a hook bounce (bolter) over the pendant. This emergency back-up is applicable to both hook-equipped aircraft and deadload operations. In aircraft operations, however, the runway pendant would not be supported on the stanchion, but by standard pendant supports on the runway surface. Where the aircraft is not hook equipped, a net must be installed on the back-up system. The energy absorbers could be installed in below surface pits which would leave only the wooden stanchions as a potential hazard to manned aircraft. See Figure 83 as possible means of mounting the emergency arresting system.

The facility expansion is explained in further detail, by Figure number in the paragraphs which follow.

3. FIGURE 83 (SHEET 1 OF 7)

This illustration is a general layout of the facility showing existing installations as well as those installations required in the facilities expansion program. Details of proposed installations are shown on subsequent sheets.

4. FIGURE 83 (SHEET 2 OF 7)

Cross sections through the proposed keel strip are shown in detail. Section "B-B" is taken through the proposed runway extension and shows a typical conduit installation. While this is shown in the proposed extension it is applicable to any station along the track where it is required for electrical or other service lines to cross the track. Section "C-C" is taken through the normal runway area.

The rails forming the guidance system in the keel strip are special extruded construction shapes as shown in Figure 57. Reinforcing rods are welded to the rail at intervals required by the maximum anticipated loads to be imposed on the guidance system. The nine foot center-to-center distance of the sets of rails is only tentative at this time. Detailed design and stress investigation may alter this dimension to a greater or lesser degree.

5. FIGURE 83 (SHEET 3 OF 7)

As previously discussed in this study the weight and speed requirements of a test program vary and therefore it may be more economical to have the capability to vary the length of the acceleration stroke. For this purpose alternate holdback positions are provided along the track. The jet car holdback was therefore designed to fit the track such that it can be unbolted and moved along the track to the various holdback positions. See Figure 85. The flat head screws are removed from the holes in the track at the selected holdback position. The holdback is positioned over the holes and secured in place. The flat head screws are installed in the track at the unused holdback positions to serve as protective plugs. The holdback is a welded "A" frame structure which mounts an air actuated release cylinder similar to that shown in Figure 85.

6. FIGURE 83 (SHEET 4 OF 7)

Provision is made, in the proposed facilities expansion program, for an unguided test vehicle. This is accomplished by installation of a ramp section as shown in Section "E-E" located at station 55 + 44. From this point on, the guide track is made in removable sections as shown in Section "A-A". These sections are manufactured of  $9 \times 3\frac{1}{2}$  inches  $\times$  23.9 pound channel welded together. Vertical restraint is provided by one inch diameter bolts into the flange of a short section of  $8 \times 8 \times 43$  pound wide flange beam imbedded in the concrete. The number and spacing of these beams will be determined by the maximum anticipated load. Lateral restraint is provided by two  $9 \times 2\frac{5}{8}$  inch  $\times$  20 pound channels welded to the wide flange beam adjacent to each side of the track assembly.

7. FIGURE 83 (SHEET 5 OF 7)

The transition from guided to unguided test vehicle is made by a ramp which imposes a gradual up load on the guides of the test vehicle. This load is sufficient to rotate the spring loaded guide to the stowed position. The ramp assembly is constructed of steel vertical plates and a horizontal plate placed diagonally fore and aft as shown. The width is the same as the removable track section to facilitate installation in the keel strip.

8. FIGURE 83 (SHEET 6 OF 7)

In the event of a primary arresting gear failure or other malfunction a back up arresting gear is provided in the proposed facilities expansion program. The proposed system consists of two concrete energy absorber foundations sized as required by anticipated loads, energy absorber size, and environmental conditions. Two energy absorbers sized according to anticipated energy levels are installed on the foundations. The energy absorbers are connected by nylon purchase tapes through a steel runway pendant supported in an overhead position by telescoping steel poles at the runway edge as shown. Intermediate support for the pendant is provided by expendable wood supports placed across the runway as required.

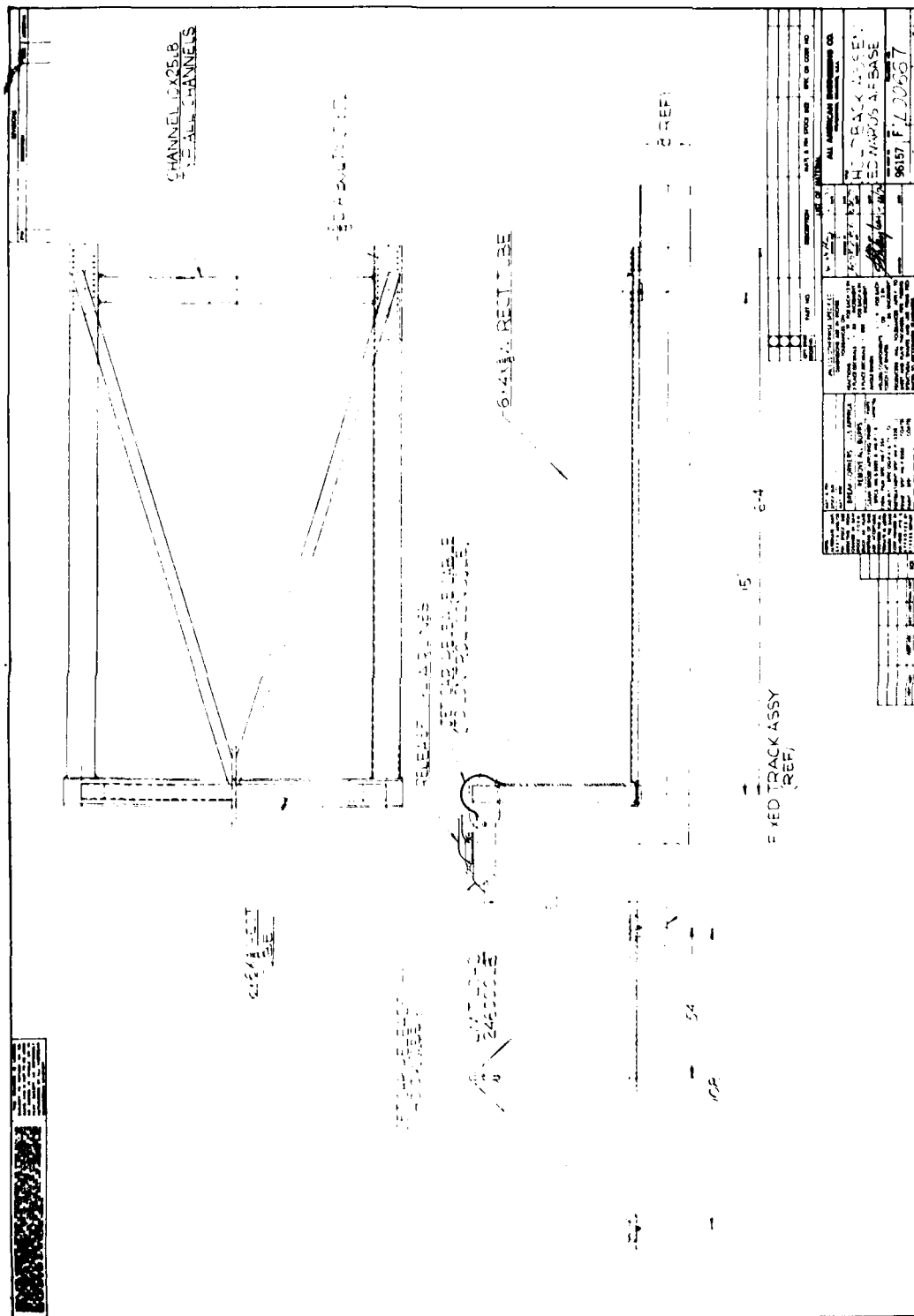


Figure 85. Holdback Assembly

For live aircraft operations the pendant is placed on standard pendant supports for hook engagement with those aircraft so equipped. For those aircraft not hook equipped a barrier net may be installed.

9. FIGURE 83 (SHEET 7 OF 7)

In order to operate with deadloads in the standard configuration of an aircraft type hook picking up the pendant off the runway surface, provision must be made for the test vehicle guides to pass over the pendant without damage if the unguided test vehicle configuration is used. To accomplish this a special ramp must be provided in the track as shown. The track is cut out to provide a hold-down area opening to a ramped exit slot, to allow pendant to be pulled out after engagement.

10. FIGURE 85

The holdback assembly is constructed with structural shapes of nine inch commercial channel, 6 inches  $\times$  6 inches  $\times$  3/8 inch rectangular tubing and 6 inches  $\times$  4 inches  $\times$  3/8 inch rectangular tubing. The structure is designed to span the track width and is guided in the track to facilitate relocation to the alternate holdback positions as previously discussed. An air actuated release hook is provided and bolted to the structure as shown.

Holdback loads, created by the engines of the jet car running at full power, are transmitted from the release hook through the *longitudinal diagonal truss* to the bolt cluster at the aft end of the assembly. The vertical diagonals in the forward area of the assembly resist compression loads. Since jet engines will not produce full rated thrust in the static position, as is the case in this application, a safety factor of 1.5 was applied to the maximum thrust. The design or limit load of this assembly was based on the thrust of the four engine TF-39 jet car; that is, 164,000 pounds  $\times$  1.5 or a limit load of 246,000 pounds.

To preclude premature actuation of the release hook assembly a pull type manual release must be actuated before the valve of the control console will function.

11. FIGURE 86

To reduce the size of the jet car on board fuel supply and electrical system, an external power and fuel supply is utilized for initial start-up and run-up of the jet car engines. This external supply is connected to the jet car through the disconnect panel assembly. This assembly is a frame which mounts the necessary fuel and electrical quick disconnect fittings. It is placed adjacent to a matching disconnect panel on the jet car and secured to the track surface. When the predetermined throttle setting is reached on the engines the jet car is released. As the car begins to move cables pull the fuel and electrical quick disconnects free of the jet car. The fuel quick disconnects are of the spring loaded valve type which shut off the flow of fuel automatically when the connection is broken.



At a predetermined position in the acceleration stroke it is necessary to shut the jet car engines down. This is accomplished by installation of a cut-off assembly adjacent to the track. The assembly is fabricated from standard structural shapes. The cut-off arm is placed in the horizontal position. As the jet car passes it cuts a trip wire between two extensions on the side of the jet car. When this wire is broken so is an electrical circuit which activates controls that retard the throttles and shut off fuel supply to the engines.

The cut-off as shown reflects an air operated cylinder to actuate the cut-off arm. This configuration is only required on the emergency cut-off assembly at the holdback or battery end. It is provided in the event of a premature release of the jet car. The cylinder which actuates the cut-off arm is connected to the release valve of the control console. When the release hook cylinder on the holdback assembly is actuated, so is the cylinder on the cut-off arm which rotates the arm out of the path of the trip wire. In the normal desired cut-off position the cut-off arm may be placed permanently in the horizontal position and the cylinder deleted.

#### 12. FIGURE 75

A size and cost comparison was made with the modular deadload utilizing concrete weights. As can be seen from Figure 76 the construction and other features of the two deadloads are basically the same. The steel weight deadload requires smaller frame assemblies thereby making the overall length and width less than the similar concrete weight deadload. This gain in less structural members is greatly overshadowed by the increased cost of steel weight assemblies as discussed in Section IX of this study.

#### 13. FIGURE 76

This deadload is similar to that described above and shown in Figure 76 and utilizes concrete weights. Combined with the J-79 jet car the maximum gross weight is 160,000 pounds. The gross weight of the deadload alone is 125,000 pounds.

This deadload is made up of one basic or pusher module, with a gross weight of 32,500 pounds, and three modular units with a gross weight of 30,500 pounds each. The pusher module is suspended on four aircraft type wheels and each of the three modular units are suspended on two aircraft type wheels. All wheels and tires are of the B-52 aircraft size and are mounted unsprung on shaft assemblies as shown in Figure 77. A removable caster wheel assembly is provided as shown to facilitate ground handling of the two wheeled modular units.

All the units are constructed of standard 18 inch structural channels and steel plates welded together to form a rectangular frame. The wheel shaft is passed through the side frame, wheel and inner frame and bolted in place. Guidance in the track is provided by four guide assemblies bolted to the underside of the frame. These guides may be either the fixed as shown or retractable as shown in Figure 87.





In operation the basic or pusher unit must be utilized first in front of the jet car as there is no provision for the modular units to be attached to the jet car. The coupler assembly as shown is utilized between the pusher unit and the modular units. It is rigid connection between the pusher unit and the first modular unit and the last two modular units. The connection between the center two modular units will be flexible.

The weight of each module is varied by removing or adding, to a maximum of ten, 2500 pound concrete weights as shown in Figure 72. A steel tube is inserted through the hold down lugs on the deadload frame and the lift lugs on the concrete weights thus retaining the weights in the deadload.

14. FIGURE 65

The deadload depicted in this illustration is a 175,000 pound maximum gross single unit deadload. The construction of the deadload is basically the same as that discussed for Figure 75. It is designed for utilization of concrete weights.

15. FIGURE 74

The deadload depicted on this illustration is a single unit deadload with a maximum gross weight of 750,000 pounds. Again the construction is basically the same as that discussed above. It is designed to withstand a two "g" load in all directions. The physical size, however, is somewhat impractical from the standpoint of handling, both for operation and maintenance.

16. FIGURE 77

The design common to all deadloads is that of an unsprung suspension system. The shaft or axle as depicted on this drawing is common to all deadloads. The design is based on the heaviest deadload with a two "g" load factor applied in all directions.

17. FIGURE 72

As previously discussed in Section IX of this study, a concrete weight assembly as depicted in this illustration is most desirable from the standpoint of overall cost. It is constructed of 9 inches  $\times$  15 pound structural channel, reinforcing rod and 2500 psi concrete mix. The channel is welded to form an open end frame. Two "U" shaped lifting rods are welded to the bottom channel. This assembly is placed in a form and concrete mix poured to complete the weight. When the weights are placed in the deadload a steel tube is inserted through the hold-down lugs on the deadload frame and the lifting rods of the weight to hold the weights in place.

18. FIGURE 88

The hook installation, as depicted on this illustration, is for the 175,000 pound deadload. It is, however, typical of a hook installation on any of the deadloads discussed in this study. It consists of a hook point, hook shank, trunnion box, tiedown cables and necessary mounting supports. The unit is constructed in such a manner that it is easily removable for installation on other deadloads.

In operation the hook assembly is positioned such that the hook point is the desired height from the runway surface. It is held rigid in this position, through shear bolts, by the support cables. When the hook engages the runway pendant the resultant load shears the bolts and the hook becomes free to move in any direction. This is accomplished through the universal type trunnion box and is required due to the reaction of the hook to dynamic loads of the arrestment. The bottom platform with its shock absorption material is provided to prevent the hook from striking the runway.

This assembly is designed in such a manner that overhead engagement of the pendant is possible by inverting the hook shank and point. In this configuration the deadload passes under the pendant. The hook is held at the required elevation by the support cables and a section of thin wall tubing between the bottom platform and the hook shank. When the hook engages the pendant the resultant load collapses the tubing and the tube not being secured to the deadload falls away. The shear bolts of the cables are also sheared and the hook is free to move in any direction.

19. FIGURE 89

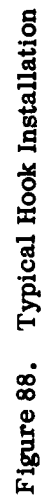
This drawing depicts the hook point utilized in the assembly described above. It is a contoured aircraft type hook point patterned after the standard U. S. Navy hook point. The maximum design load is 700,000 pounds. It is an expendable item which is easily removed and replaced when wear or other damage dictates.

20. FIGURE 90

This illustration depicts the hook shank utilized in the hook assembly described above. It is designed for a maximum load of 700,000 pounds with the shear forces taken out through the material behind the hook point mounting surface.

21. FIGURE 91

As the size of the deadload increases, the loads imposed on the hook assembly increase thus requiring the size of the hook to increase. This hook shank is designed for use with the 750,000 pound deadload. It is similar in design to the hook shank shown in Figure 90 with a load limit of 1,500,000 pounds. Here again the shear forces are taken through material behind the hook point mounting surface.



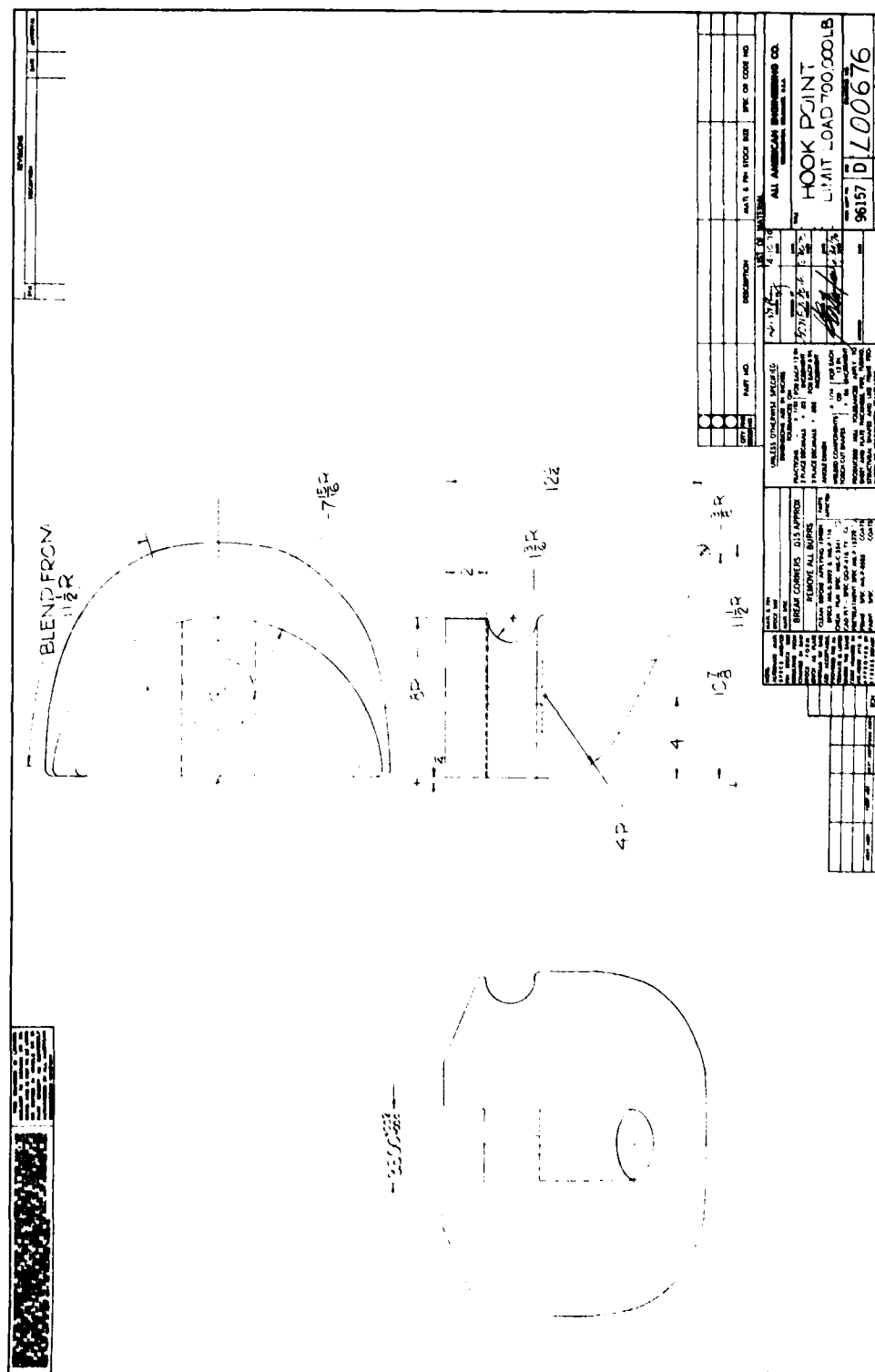


Figure 89. Hook Point - 700,000 Lbs.

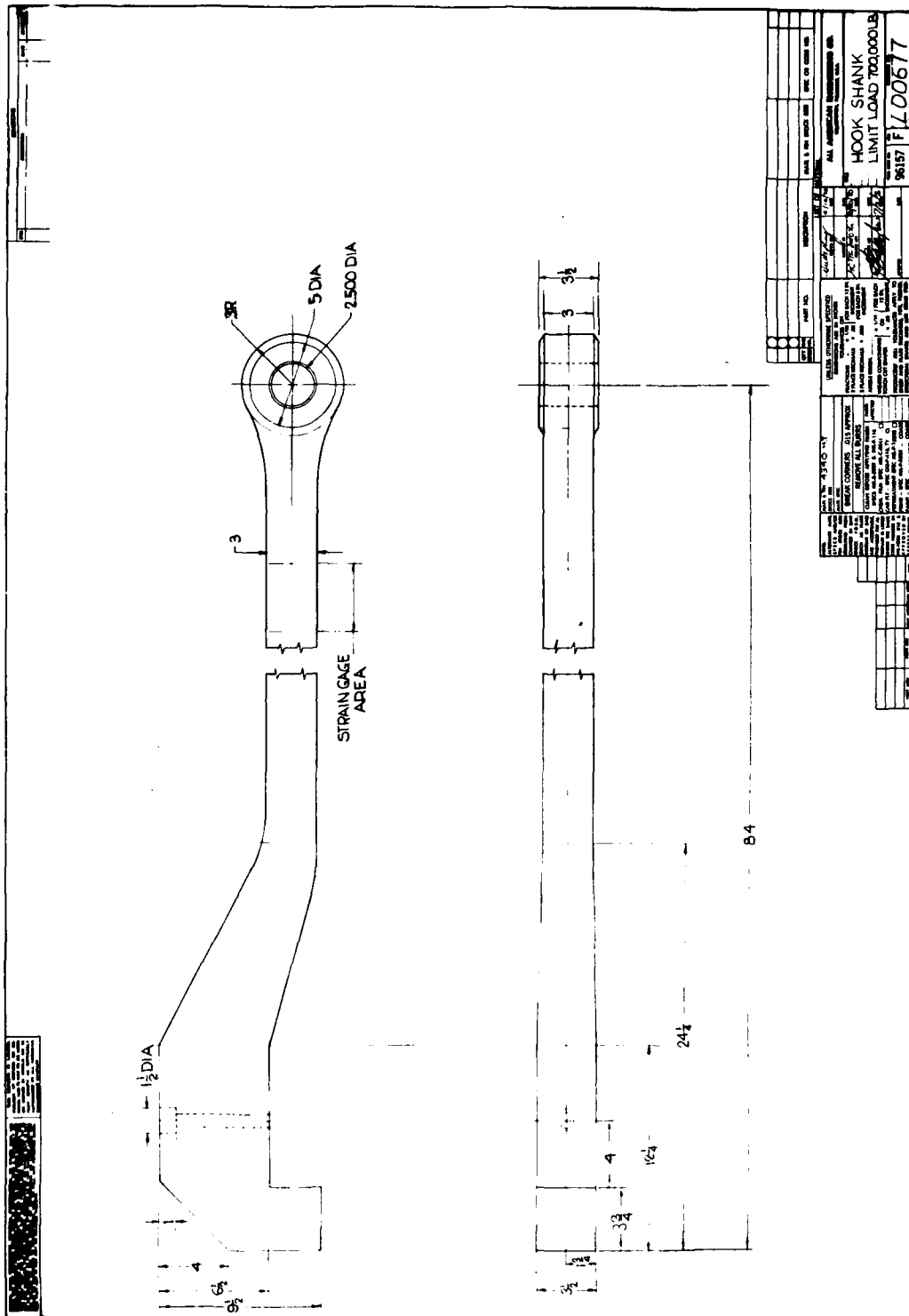


Figure 90. Hook Shank - 700,000 Lbs.

22. FIGURE 92

The hook point as shown is patterned after U. S. Navy hook points as was the case with Figure 89. This point, however, has a design limit load of 1,500,000 pounds and will require considerable testing to fully develop the design. It is designed for use with the hook shank described in Figure 91 above.

23. FIGURE 78

The deadload as depicted on this illustration is a modular deadload with a maximum gross weight of 680,000 pounds. Coupled with the jet car a maximum gross weight of 750,000 pounds may be obtained. It consists of four modular units each with a minimum weight of 30,400 pounds and a maximum gross weight of 170,400 pounds. The basic construction is the same as that described in Paragraph 13 except each module is suspended on four wheels.

24. FIGURE 68

This illustration depicts the conceptual design of the TF-39 jet car. The basic structure of the car is square steel tubing welded to form an aircraft type frame work which houses and supports four TF-39 turbojet engines. It contains the necessary onboard equipment of fuel tanks, batteries, electrical system, throttles and fuel cut-off system for short term operation of the engines. The total weight of the car is estimated to be 65,000 to 70,000 pounds. The engines have a static thrust of 41,000 pounds each producing a total thrust of 164,000 pounds at standard conditions.

The car is suspended on aircraft type tires and wheels of the size used on F-100 and F-106 aircraft. The wheels are unsprung and non-steerable. A total of eight wheels are utilized to support the car on an outboard tread width of 448 inches. The use of aircraft tires and wheels recommended for the deadloads should be considered in the detail design of the jet car since logistics would be simplified if the jet car and deadload wheel sizes were identical.

The car is retained and guided through the acceleration stroke by four retractable or stationary guide assemblies. These guides are shown in detail in Figures 76 and 87. A series of vertical and horizontal slippers provide rubbing surfaces which carry the guide loads into the car frame.

Fore and aft loads are imposed on the car from jet engine thrust and the arresting gear. Vertical loading is present as a result of runway surface variations and ground effects of air flow which cause the car to bounce. This load is reacted through the loading of the horizontal slippers on the upper flanges of the guide beams. Lateral loading is present as a result of track irregularities, crosswind conditions, and tracking characteristics of the jet car. The car is designed for a two "g" loading in all directions based on 65,000 to 70,000 pounds gross weight.

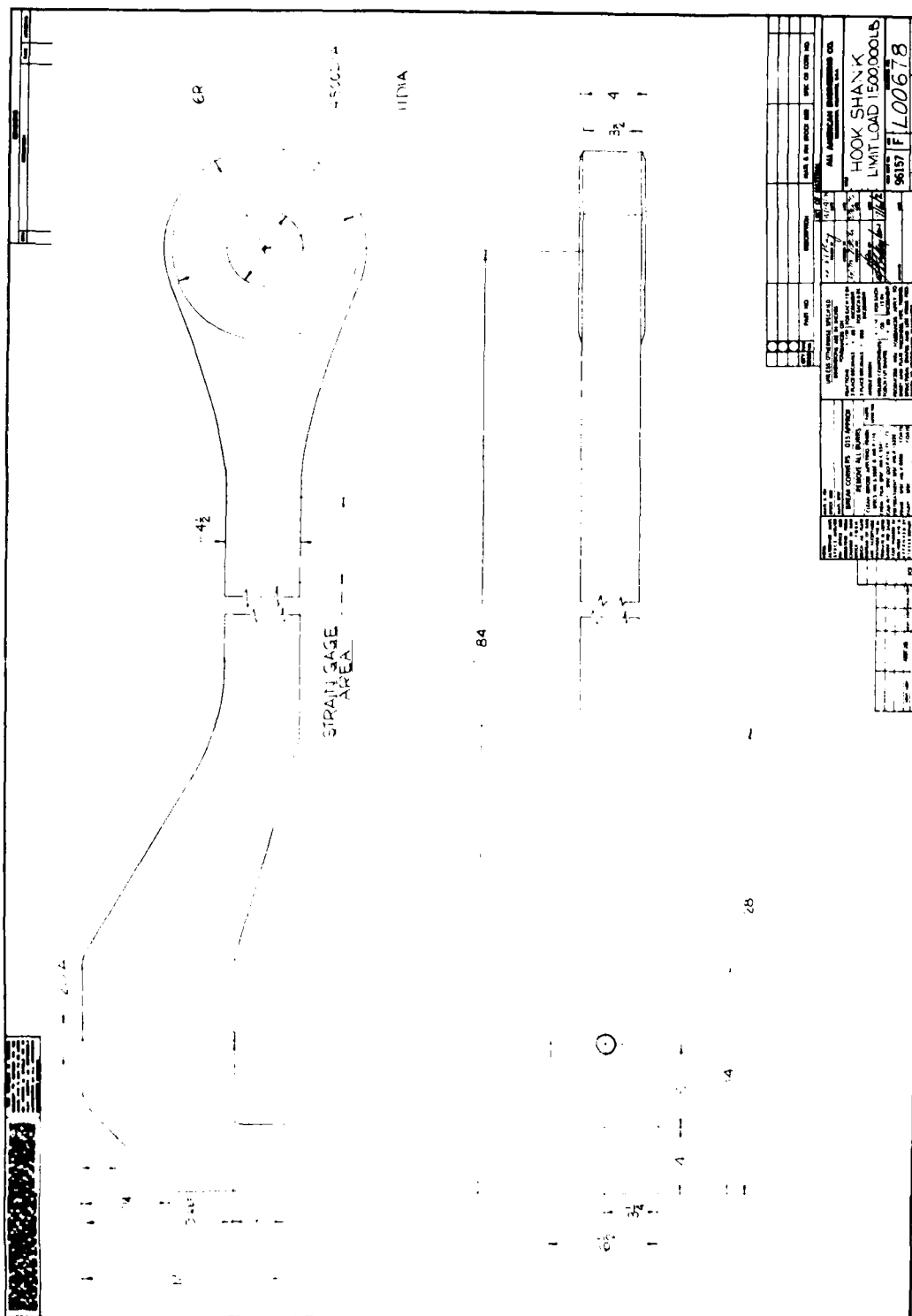


Figure 91. Hook Shank - 1,500,000 Lbs.



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ALL AMERICAN ENGINEERING CO WILMINGTON DE  
FEASIBILITY AND CONCEPTUAL DESIGN STUDY TO ADD A DEADLOAD TEST --ETC(U)  
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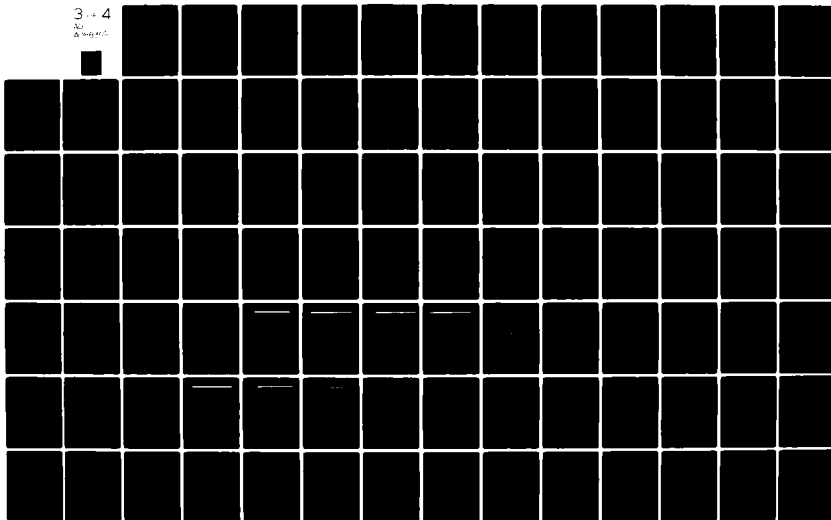
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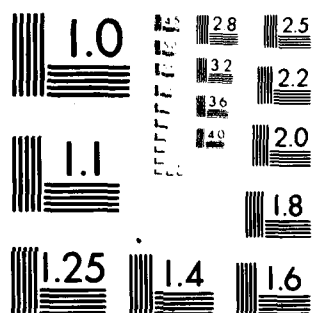
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The arresting hook, emergency hook, and chassis must be designed to withstand the loads of the combined weight of the deadload and the jet car with a safety factor of two. In this case a design limit load of 1,500,000 pounds was determined. The holdback fitting structure is designed for a limiting load of the combined thrust of the engines plus a safety factor of 1.5 or 246,000 pounds.

## 25. FIGURE 67

The conceptual design of the J-79 jet car is depicted in Figure 67. The car's basic structure is square steel tubing welded to form a typical aircraft type space frame work which houses and support six J79-5 turbojet engines. Equipment necessary for short time operation of the engines is included within the structure. This equipment includes fuel tanks, batteries, an electrical system, throttles, and a fuel cut-off system. The engines have a static thrust rating of 15,600 pounds with afterburner. The estimated total weight of the car is 45,000 to 55,000 pounds.

Since there is not a requirement for sprung wheels, the wheel suspension is solid. The tires and wheels are Air Force type  $30 \times 8.8$  and are used on F-100, F-102, and F-106's. The tires have a rating of 250 miles per hour and a static load rating of 21,000 pounds at an inflation pressure of 320 psi. The tread on both front and rear wheels is 121 inches.

The car is retained and guided through the acceleration run by four retractable or four fixed, heat treated guide assemblies. These are similar to those shown in Figures 87 and 76 respectively. A series of vertical and horizontal slippers provide rubbing surfaces which also carry the guide loads into the car frame.

Fore and aft loads are imposed on the car from jet thrust and the arresting gear. Vertical loading is present as a result of runway surface variations and winds which can cause bouncing of the car. This is reacted by the loading of the horizontal slippers on the upper flanges of the guide beams. Lateral loading is present through track irregularities, cross wind conditions, and tracking characteristics of the jet car. The car should be designed for a two "g" load in all directions based on 40,000 to 50,000 pounds gross weight.

The arresting hook, emergency hook, and chassis should be designed to withstand the loading of the combined weight of the deadload and jet car with a safety factor of 2. This is accomplished by adding shear webs on the floor frames and main frames at BL-0 to distribute the load. The 12 inches  $\times$  4 inches  $\times$  3/8 inch rectangular tube through BL-0 will carry the two "g" arresting load from the deadloads through the jet car and into the hook. Both emergency and operational hooks should be designed for a limit load of 300,000 pounds.

The holdback fittings should be designed for the combined thrust of the engines with a factor of 1.5.

26. FIGURES 69 THROUGH 71 AND 93

The control system as proposed for the jet car provides monitoring instruments for critical engine data, remote operation of the engines and an automatic speed control input. The controls are housed in a standard 19 inch relay rack sloped front control console and are connected to the jet car through an umbilical cord. The control console can be situated up to a maximum distance of 200 yards from the jet car itself. The controls are designed to handle up to eight engines.

The power requirements for the control system are 110 volts single phase 60 hz at the console (approximately 500 watts) and a 28 VDC Nickel cadmium battery on the jet car itself. The 110 volts is converted to 28 VDC with a power supply in the panel that also acts as a battery charger when the car umbilical cord is connected and the panel is energized. The battery on the car serves as the power source for shutdown of the engines at the end of a run, and as a power source for the automatic speed control.

The monitoring instruments are packaged in plug-in modules so that if any instrument for a particular engine malfunctions, all instruments are replaced for that engine by simply replacing the instrument module. Each instrument is a dual reading instrument so actually one module contains all the instruments for two engines. The data that is monitored is:

- a. Percent rpm
- b. Fuel flow
- c. Exhaust gas temperature
- d. Oil pressure

The operating controls include an engine select switch which connects the throttle, ignition, and start controls to a particular engine. The throttle controls are momentary pushbutton switches that advance or retard the throttles with an electrical actuator on each engine throttle. The starter control operates a solenoid air valve at each engine to operate the engines start motor. The ignition controls supplies, through a relay, the necessary voltage for the engines ignition system. In addition to the individual throttle control through the engine select switch, there is an alternate action switch that connects all actuators simultaneously to the advance retard controls.

The other operating controls include an arm for release and a release switch, and an emergency stop switch that stops fuel to all engines in the event, that for any reason, the operator finds it necessary to shut down all engines.

The remaining control is a digit-dial switch with which the operator can preselect the desired speed into an automatic speed control on the jet car. In conjunction with this control is a switch that selects either automatic or manual control.

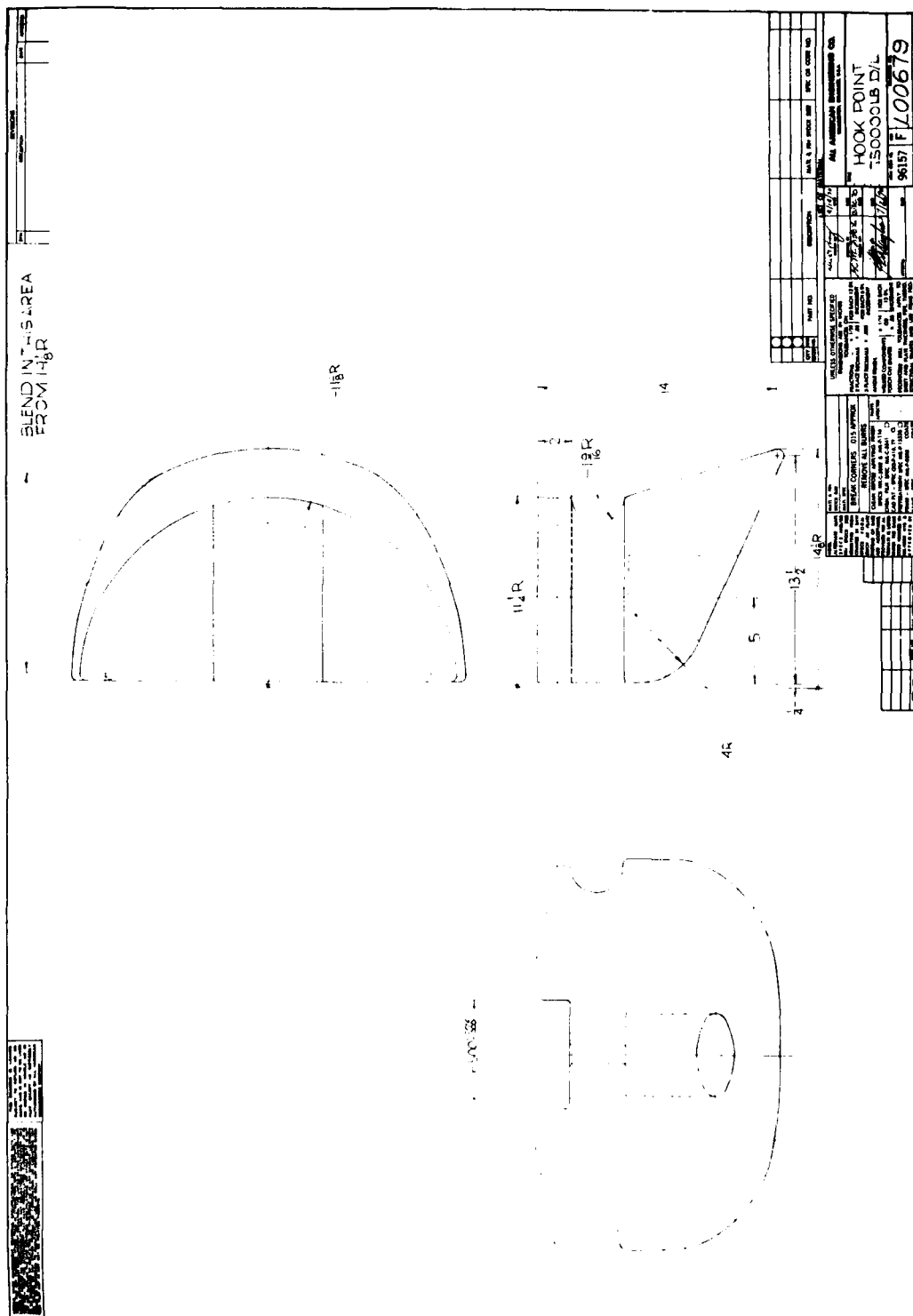


Figure 92. Hook Point - 750,000 Lbs.



During a typical operation the control operator would assure that the jet car battery is turned on and that the umbilical cord is properly connected. The operator would then turn on the console power and select an engine for starting. After the engine is selected the operator would press the starter switch and monitor rpm. As the rpm builds up he would turn on the ignition and advance the throttle to obtain the correct fuel flow for starting. After the engine started the ignition would be turned off and the throttle adjusted to give proper idle rpm. This process would be repeated until all engines were running.

The operator would then set the desired speed into the speed control and switch from manual to automatic control and arm the release. Upon operating the release control, the throttles would advance to 100% rpm and hold there until the desired speed was reached. As the desired speed is approached, the throttles would retard to the level that would maintain the pre-selected speed.

27. FIGURE 66

This illustration depicts a simulated 707 aircraft deadload. This deadload was designed and manufactured by this contractor for use in a previous test program not connected with this contract. It is presented here to demonstrate a variation of a deadload configuration which is economically feasible for use in test programs.

28. FIGURE 73

This deadload is a single unit frame identical to that shown in Figure 74 except for a structural integral water tank. The water tank was constructed with baffle plates to reduce the effects of sloshing. The maximum gross weight of this deadload is 750,000 pounds. It is, however, considered not feasible for this application due to cost and design problems inherent with utilization of a large volume of water as ballast.

29. FIGURE 84

This illustration depicts an artist's conception of the overall finished appearance of the proposed test facility. Pictured at the battery end in the holdback is the jet car and modular deadload ready for launch. A mobile operations trailer, electrical power supply, and fuel trailer are readily available. All being trailer mounted, they provide the mobility necessary to meet varying test operations. The warning system consists of flashing revolving lights and horns strategically located to give adequate visual and sound warnings when testing is in progress.

30. FIGURE 87

The retractable guide assembly consists of a guide, similar to the standard stationary guide, pivoted between two side plates. A spring or bungee is used to load the aft end of the guide against the upper flange of the guide rail. When the guide engages the ramp, Figure 83, this load is sufficient to retract the guide and

hold it in the stowed position clear of the runway. This design may be sized and modified to suit the load conditions of any jet car or deadload.

31. FIGURE 95

The jet car contains an integral onboard fuel system. The tanks are filled through the jet car disconnect panel by opening the tank fill valve and pumping fuel until it flows from the vent lines. When the tanks are full, move fuel fill valve to closed position. Continue to pump fuel through disconnect panel to start engines. The fuel for starting and running of engines in the battery position is supplied from the external source due to the system of check valves. When the car is released and moves away from the disconnect panel the fuel is free to flow from the jet car tanks to the engines.

32. FIGURE 94

The 300,000 pound limit load jet car to deadload connector assembly is manufactured from structural shapes, 18 inches  $\times$  58 pound channels and mild carbon steel plates as required. The stabilizer bars are square steel tubes. This unit is designed for loads derived from pushing and stopping the deadload. Due to clearances, top and bottom of the connectors, the deadload or jet car is free to move vertically, independent of each other.

33. FIGURE 71

See Paragraph 23.

34. PRELIMINARY STRESS ANALYSIS

A preliminary stress analysis was performed as a structural check on member sizes which were selected for the deadload, track and the J-79 jet car. The data generated appears in this report as Appendix IV. This preliminary analysis should not be interpreted as anything other than a brief, cursory determination of the integrity of certain structural components.

The deadload module as depicted in Figure 78 demonstrated for the configuration presented, subject to a two "g" load in any direction, would be structurally adequate with minor adjustments at frame joints. The towing structure was not investigated for this preliminary effort because it appears not to pose any problem.

A fixed track as shown in Figure 83 analysis indicated it would be structurally adequate.

The proposed removable track as shown in Figure 83 is worthy of future consideration as a housing for the ramps which are required to deflect the deadload guides upward. As presently designed they are not practical for more than







**Figure 95. Fuel System Schematic - J-79 Jet Car**

a short length due to the multitude of fasteners, i.e. on four inch centers required for anchoring.

The initial truss work performed on J-79 jet car (Figure 67) indicated that presumed structural members are adequate. No investigation was performed for the pusher bar, overrun hook, holdback fitting, or arresting hook as these items should pose no problem.

A firm design criteria must be generated to allow for justification of a detailed stress analysis.

## SECTION XI

### IMPLEMENTATION PLAN

The object of this section, of the study, is to present an orderly plan whereby the full capabilities of the existing facility may be realized. The proposed facilities expansion program is a step by step plan to obtain maximum required capabilities of the facility as planned requirements dictate. In order to accomplish this the first three steps must be initiated and in process concurrently to meet present and short range requirements. The remainder of the steps may be accomplished concurrently or in programmed sequence to meet long range requirements.

#### 1. KEEL STRIP & GUIDANCE SYSTEM

The first step in the proposed facility expansion program is the construction of the 18 inch thick by 50 foot wide concrete center section, or keel strip, of the existing runway. This strip will contain two integral sets of guide beams, flush mounted in the concrete as shown in Figure 55, to provide the guidance system necessary for deadload operations. The installation of this portion of the proposed facility will allow subsequent manned aircraft and deadload testing operations without costly breakdown or set-up time. This is the key step in the proposed facility expansion program to provide the testing capability with both manned aircraft and deadloads for both Air Force and commercial aircraft throughout the full range of requirements, present and envisioned over the next decade. Without this initial step, the full potential of the facility cannot be realized. It is suggested that the proposed 2000 foot extension to the runway which will ultimately be required for simulation of commercial transport aircraft be installed at the same time assuming that funding would be available at the time.

#### 2. JET CAR, DEADLOADS AND SUPPORT EQUIPMENT

##### a. Propulsion System

The second step in the proposed facility expansion program is the detailed design and construction of the propulsion system. A six engine J-79 jet car, similar to the four engine car, shown in Figure 67 is sufficient to meet existing and short range requirements. With an integral hook it can function as a deadload for operations in the 40,000 to 50,000 pound weight range. By attaching a deadload of 125,000 pounds (see Figure 75) and arresting the jet car as part of the deadload a weight range of 46,000 to 174,000 pounds may be realized. This is sufficient to meet the requirements of the tests to be conducted for the proposed supersonic interceptor.

b. Deadload

The third step in the facility expansion program is the detailed design and construction of two deadloads. The 750,000 pound modular deadload, shown in Figure 76, is sufficient to meet existing and long range requirements for weights above 50,000 pounds. For operations in weight ranges below 50,000 pounds, the standard method of jet car pushing the deadload and stopping the jet car independently may be used. In this case a basic deadload is required with a weight range of 6200 to 32,500 pounds. In operations 50,000 pounds and above, the jet car is arrested as part of the deadload.

c. Associated Support Equipment

Not a separate step in the facility expansion plan, but one which should be accomplished concurrently, is that of providing the necessary associated support equipment. The control console, power and fuel supply equipment must be provided for the jet car. For both the jet car and deadload the on-board instrumentation and power supply for same must be provided. To operate with a deadload and jet car the holdback, quick-disconnect panel, and engine cut-off assemblies are required. If the jet car is to be arrested independently of the deadload, the energy absorber for the jet car is required. An emergency back-up arresting gear should be provided in the event of malfunctions or failures.

3. PROPULSION SYSTEM, LONG RANGE REQUIREMENTS

The final step in the facility expansion program is the detailed design and construction of a propulsion system to meet long range requirements. Projected new aircraft and arresting gear development tests, as shown in Section V, Table 3, will require the ability to accelerate weights of 728,000 pounds to a maximum velocity of 142 knots. In order to accomplish this, the four engine TF-39 jet car, as shown in Figure 68 is required. This propulsion system could also be incorporated as Step No. 2 thus eliminating the requirement for the J-79 jet car.

## SECTION XII

### CONCLUSIONS AND RECOMMENDATIONS

The arresting gear test facility at the AFFTC and the Naval Air Test Facility, Lakehurst, N.J., cannot meet the Air Force requirements for category II aircraft arresting gear system testing within the full range of weights and speeds of aircraft now in the Air Force inventory. A facility to meet these requirements has never been built. Planned procurement of new aircraft will make the present arresting gear test facility more obsolete.

1. An aggressive military construction program should be initiated to maintain a test capability compatible with future aircraft purchases.

The wide range of aircraft weights and speeds, which AFFTC should be capable of simulating or testing, now and in the future, will demand a test facility capable of simulating ten to twelve times the energy limits of any present test facility.

Take-off energy levels of the F-4, FB-111 and the proposed supersonic interceptor can be simulated utilizing a six engine jet car and deadload combination with J79-5 engines based on predicted performance at 2500 foot altitude on a 59 degree day within the presently available 5800 foot acceleration stroke. Based on the same performance data the energy levels for the B-1 advanced manned strategic bomber and the C-5A aircraft could be simulated utilizing a six engine TF-39 jet car. Both of these conclusions are drawn from Figure 49. Simulation of the same energy levels could be accomplished with four engine jet cars but half again as much acceleration stroke would be required. Alternatives to the use of a six engine car as opposed to four are the following:

a. Add a 2000 foot long by 50 foot wide by 18 inch thick runway extension at the battery end of the existing runway at an estimated cost of \$364,000.

b. Supplement the available thrust of the proposed J-79 engines by the use of one or more rockets. The impulse required to augment a jet car to increase the velocity from 206 to 235 knots for a 150,000 pound simulated aircraft is 228,000 pound seconds which would cost an estimated \$18,000 per test event.

2. Of the several approaches considered, the most practical would be the acquisition of one small module, two larger deadload modules, and a six engine J79-5 jet car to simulate the energy levels through the proposed supersonic interceptor. To minimize hardware acquisition costs, the J79-5 jet car frame should be designed to house the TF-39 engines when these are required. Follow on acquisition of two other large deadload modules would allow the simulation of the remaining larger Air Force aircraft as well as most large commercial aircraft. This conclusion is based on performance for a 59 degree temperature which would occur only in the early morning or evening hours of the warmer months of the year.

Several deadload concepts were considered and designed on a preliminary basis. Included were unitized and modular deadloads which contained water, concrete, or steel ballast to vary the weight as desired.

3. Based primarily on handling convenience, the use of a modular deadload is recommended. Based on cost considerations the ballast material for weight variation should be concrete as opposed to steel.

Of the many electronic and mechanical systems considered for deadload and jet car guidance, the electronic systems have been determined to be impractical because of the requirement to make all deadload and jet car vehicles steerable or otherwise capable of changing their tracking direction. The most practical guidance system consists of two parallel track pairs of a special structural shape imbedded in the proposed thickened center section of the runway.

4. The utilization of two as opposed to one mechanical guidance system is recommended as a redundant safety feature because of the heavy deadload weights that must be constrained.

The conceptual design of the facility generated as part of this study lends itself to a step-by-step process of construction and/or procurement. The most important and also the primary step which must be done is the construction of the keel strip and the concurrent installation of the flush guide beams.

5. Of the two basic methods of facility construction, i.e., fixed and mobile, it is recommended that no new fixed facilities be added at the AFFTC but rather all ancillary facilities necessary for jet car operation be mobile.

APPENDIX I

CORRESPONDENCE AND DATA



APPENDIX I  
CORRESPONDENCE AND DATA

Item Number	Table of Contents Description	Page
1.	Letter, Department of the Navy, Naval Air Test Facility, 4200, dated 30 April 1970.	184
2.	Frances D. Akins, Arresting Gear High Cycle Tester, Naval Air Technical Journal, Vol. 3, No. 4, Unclassified.	190
3.	Letter, R. H. Hopps, Lockheed, California Company, dated 1 April 1970.	192
4.	Letter, W. E. Parsons, Douglas Aircraft Company, dated 24 March 1970.	193
5.	Letter, P. L. Peoples, The Boeing Company, dated 27 April 1970.	195
6.	Letter, G. C. McIntosh, All American Engineering Company, dated 5 March 1970 (to Hercules Powder Co.).	196
7.	Letter, G. C. McIntosh, All American Engineering Company, dated 5 March 1970 (to Thiokol Chemical Corporation).	197
8.	Letter, G. C. McIntosh, All American Engineering Company, dated 5 March 1970 (to Aerojet General Corporation).	198
9.	Letter, J. W. Chamlee, Thiokol Chemical Corporation, dated 25 March 1970.	199
10.	Letter with Attachment, L. E. Morey, Hercules Incorporated, dated 21 April 1970.	200
11.	Letter Quotation, N. L. Fimple, Bethlehem Steel Corporation, dated 26 March 1970.	202
12.	Georgetown Test Facility.	207

DEPARTMENT OF THE NAVY  
NAVAL AIR TEST FACILITY

NAVAL AIR STATION  
LAKEHURST, NEW JERSEY 08733

IN REPLY REFER TO  
4200  
30 APR 1970

All American Engineering Company  
Post Office Box 1247  
801 South Madison Street  
Wilmington, Delaware 19899

Attention: Mr. G. C. McIntosh  
Sr. Project Engineer

Gentlemen:

The following information is submitted per your request of March 12, 1970. This information is forwarded to assist you in fulfilling your contract with the U. S. Air Force with regard to a deadload facility at Edwards Air Force Base.

A. Description of Facility and Equipment

1. A Recovery System Track Site (RSTS) consists of a double-rail jet car track that is used for testing the various arresting gears or components, plus barriers, barricades or components, and aircraft components.

2. A four-wheeled jet car, powered with J-48 engines, is used as a launching device and source of energy. Present jet cars are arrested by a system of trailing friction brakes which, at the end of the launching run, engage a thickened section of track rail. Braking force is adjustable up to a maximum of 13,000 pounds per brake unit.

3. The characteristics of a typical track site at NATF are as follows:

Reinforced concrete	
Length (in feet)	7,800
Track width (in feet)	28
Free-run width (in feet)	40
Slab thickness (in inches)	12
Design strength of wheel load (in pounds)	54,000

Guide rails	
Length (in feet)	7,408
Cross section (inches WF 49)	10
Spacing, centerline (in inches)	52-1/2
Brake rail (movable) (length in feet)	900
Runout area	
Paved length (in feet)	1,400
Paved width (in feet)	200
Cleared over-run area (length in feet beyond the paved area)	1,000

4. The model 656 (modified) jet car characteristics are as follows:

Engine (four)	J-48-P-8
Number of wheels	4
Tire size (inches)	30 x 7.7
Thrust (pounds)	24,000
Fueled weight (pounds)	18,000
Length	21 ft 4 in.
Width	17 ft 7 in.
Maximum speed (knots)	260
Maximum design deceleration (G)	8

5. At the launch end of the track site, there is a control building from which the jet engines are started and brought to required RPM to obtain the desired thrust for the particular test event. Two buildings are located at the arresting end of the track site. One building houses the data recording equipment while the other serves as a work area for the maintenance of the arresting gear.

6. In addition, two backup arresting gears are installed in the runout area. One gear is for the purpose of arresting a runaway deadload should the primary gear fail, while the other is used as an anti-coastback device to protect the facilities if the deadload were to walkback excessively.

B. Method of Operation: An engineer from the Recovery Division is in charge of the test program. A Site Officer (Naval) is charged with the duties of coordinating the launch and recovery ends of the track sites and acting as Safety Officer. The Site Officer is in contact with the launch end by sound-powered phones. When assured that the recovery end is ready, he prepares the site for test and relays the RPM requirements to the launch end to obtain his desired end speed as per the test directive. He gives the word to release the jet car and also announces when the test is complete.

C. Manning Figures: The following personnel have to be available to operate and maintain a track site (the personnel marked with an asterisk, however, are required only on a part-time basis):

1. Five Aircraft Launching and Arresting Devices Mechanics to operate and maintain the arresting gear under test, the back-up arresting gears and serve as road and fire watchers during tests.

\*2. Two Aircraft Launching and Arresting Devices Mechanics to maintain and repair deadload and arresting-gear components.

3. Three Aircraft Engine Mechanics to operate and maintain jet engines and jet cars.

\*4. Two Aircraft Engine Mechanics to maintain brakes, overhaul jet engines, and repair jet car components.

5. One Supervisor.

\*6. One Tractor Operator to push deadloads and jet cars back to launching end of track site.

\*7. Four Electronic Technicians at Recovery end of track site to operate data recording equipment.

\*8. Six Electronic Technicians for support services in maintaining and installing data recording equipment.

\*9. Two photographers to record test events.

\*10. Two laboratory personnel to process filmed data.

11. One Test Engineer.

\*12. One Material Personnel to obtain and issue components for repairs, installation, and maintenance.

13. One Site Officer (Military).

D. Capability of Facility

1. It is presently possible with the J-48 jet car to launch a deadload to obtain a potential energy capacity of 79 million foot-pounds. For tests requiring higher energy levels than those presently obtainable with the J-48 jet car, additional launching energy is obtained by installing JATO units on the test vehicle. By increasing the number and size of the JATO units, it is possible to significantly increase the energy levels.

2. In view of the higher energy requirements necessary for future test operations, NATF is presently modifying an existing jet car to utilize J-79 engines as a source of power. This modified jet car will have approximately 58 percent more energy than the present jet car.

3. For the express purpose of performing the above functions, deadload test vehicles are available to obtain any desired weight ranging from 8,000 to 110,000 pounds. Also available are deadload aircraft (stricken) used to simulate the actual entry of aircraft into an arresting system. Available are the A-4, F-4, A-3, F-111, and F-8 deadload aircraft. (The F-111 does not have a nose gear; however, a nose gear can be "jury-rigged" if a need existed.)

E. Cost of Installation and Operation: The costs listed are approximations of present day costs:

Recovery System Track Site	\$1,655,000
Jet Engine Remote Starting Building	6,000
Data Acquisition Building	25,000
Recovery Maintenance Building	22,000
Jet Car (engines and starting system assumed to be GFE)	250,000
Deadload (Type I)(8,000 - 16,000 Pounds)	25,000
Deadload (Type II)(15,000 - 35,000 Pounds)	70,000
Deadload (Type III)(30,000 - 110,000 Pounds)	125,000
Instrumentation for Data Acquisition Site	250,000
Deadload Telemetry Packages	10,000
Photographic Equipment and Electrical Facilities	19,000
Tractor (to push deadload and jet car back to launch end)	15,000
Maintenance Shop (for jet engine repair, brake overhaul)	50,000
Labor and Material costs for one day's operation (based upon sustained daily operations at NATF)	2,200

F. Description of Current "State of the Art" Equipment with its Capabilities, Deficiencies and Limitations: Since the track and jet car capabilities have been discussed under paragraph D, they will not be repeated here. The instrumentation capabilities are as follows:

1. The record and quick-look capability system available at the RSTS area is a Direct Record FM/FM Multiplex System with the following items at a site:

a. Amplex FR-100A (with ES-100 Electronics) tape system, one-inch tape with fourteen tracks

b. Time-of-day code and a six-digit identification number in BCD form, 100 pulses per second recorded as 10 KC and 13 KC Tone Bursts (Hermes Tone Burst Format)

- c. Telemetry Receivers (two each)
- d. Voltage Controlled Oscillator - 64 each (land line data channel limit) IRIG proportional BW
- e. Low-level Differential Amplifier - 40 each
- f. Transducer condition capability
  - (1) 48 Low-level (strain gage) channels
  - (2) 24 High-level channels
- g. Honeywell Visicorder Model 1612
- h. Demultiplexers - 31 each
- i. Dual-corner reflector antenna

2. Deadload telemetry packages available have up to sixteen continuous data channel capability.

3. Photographic instrumentation includes Pin registered cameras with speed ranges of 100 - 500 frames per second, high-speed cameras with speed ranges from 100 - 1,000 frames per second, ultra-high speed cameras, miscellaneous equipment including lenses, tripods, editing equipment, still and sequence cameras, battery packs and camera control systems. The laboratory equipment will not be delineated here since it is the normal equipment necessary to process the data obtained with the equipment as noted.

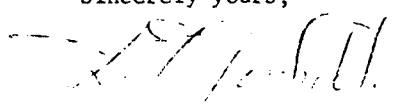
4. Coupled with the arresting gear and instrumentation equipment, support facilities are maintained and updated in order to maintain pace with the "state of the art". It is not enough to collect data; it must be analyzed and disseminated. The digital computational facility provides for scientific problem solution, management information systems, and scientific data reduction of mass data acquired at the track site. Equipment includes a CDC 160 Digital Computer, four CDC 164 tape drives, one on-line CDC 167-2 card reader, one on-line Anelex series -5 160 character printer, one on-line CDC 165-2 digital incremental recorder, one CALCOMP 565 digital incremental recorder. Inputs are prepared on two off-line Friden Model F flexowriters, one IBM model 026 keypunch and test data is digitized on one off-line CSC Microsadic Model II A/D converter. Machine language plotting routines are included.

5. In conjunction with the digital computational facility, an analog computational facility is available. Its primary function is to process and convert analog data recorded on magnetic tape to a digital format suitable for digital computer reduction. Equipment includes an Arnoux Pulse Amplitude Modulation Decommunicator, an EAI 16-31R analog computer for data manipulation of data filtering and branching networks provide for data termination in two 36-channel oscillographs and a 40-channel analog to digital converter with a gapless binary format tape. The analog computer can be operated for off-line solution of scientific problems with outputs on an X-Y plotter.

6. In order to collect accurate data, there is available an instrumentation calibration and development facility. Included in this facility is a strain gage installation shop, a transducer calibration laboratory, and an electronic calibration laboratory. This facility manufactures, calibrates and maintains electrical transducers and associated electronic data handling equipment used in support of test and evaluation of arresting devices. The major equipment used by this facility is a deadweight pressure tester, a 100 G centrifuge, a frequency generator and an electric furnace.

7. Also available is the tensile calibration test facility which has a universal tensile testing machine which has a capacity of 400,000 pounds. Coupled with the tensile tester is a function generator, a rate programmer and a curve follower to produce any type of function, cycle and tension or compression input.

Sincerely yours,

  
D. L. TOOMILL  
Captain, USN  
Commanding Officer

Copy to:  
NAVAIRSYSCOM (AIR-537)  
ASD (ASNMH-10) WPAB

## ARRESTING-GEAR HIGH-CYCLE TESTER

By **Frances B. Akins**  
**Engineering Services Division**  
**Engineering Department (SI)**  
**Naval Air Engineering Center**  
**Philadelphia, Pennsylvania**

### Unclassified

In early 1970 an Arresting-Gear High-Cycle Tester (AGT-1), designed by the Naval Air Engineering Center, Philadelphia, Pa., will be installed at the Naval Air Test Facility (SI) (NATF(SI)), Lakehurst, N.J. This 80-shot-a-day high-cycle testing system will check out and qualify new arresting gear for placement aboard aircraft carriers. Currently, a jet-engine-driven sled speeds a deadload into the arresting gear. This low-cycle testing system is time-consuming and expensive, where many arrests are necessary, and has a maximum capacity of 20 cycles a day for each sled site.

### Description

The high-cycle tester substitutes the energy of a rotating flywheel and its attached translating cable loop and shuttle for the energy of a moving deadload. Other rotating components in the drive system are a capstan and clutch.

An arresting hook is attached to the shuttle, which moves in a 640-foot guide track. Connected to the shuttle, and forming a continuous loop, are the tow cables and the trailing cables. The tow cables are wrapped around the capstan, coupling the cable loop to the rotating masses (capstan, clutch, and flywheel). The capstan is driven by the flywheel through a hydraulically actuated air-cooled dry clutch. Compensators maintain slack side tension in this cable loop, preventing slippage between the cables and the capstan.

UNCLASSIFIED

### Operation

At the outset of a test, while the clutch is disengaged, a 2,300-hp. gas-turbine engine accelerates the flywheel to desired initial speed. Operators manipulate a series of sequentially arranged controls which actuate the clutch and other AGT-1 components. All other action is automatic. Clutch actuation couples energy from the flywheel to the capstan, accelerating the cable loop and shuttle to the desired speed. When the cable loop is up to speed, the clutch locks in, and the shuttle hook engages the arresting-gear deck pendant, simulating an aircraft arrestment.

At the end of the arrestment, all the translating and rotating energy has been extracted by the arresting gear, bringing the tester to a stop. Then the clutch is released, the cable compensators relaxed, and the cable loop is returned to battery position by the retraction system. The retraction device is a small, independent cable-loop system driven by a diesel engine and capstan. While retraction is in progress, the flywheel is automatically rotated to initial speed and the tester is ready for another shot.

### System Performance Characteristics

The maximum energy absorbed during arrestment is 56 million ft./lb. The clutch dissipates 25 million ft./lb. during shuttle acceleration and the flywheel stores 81 million ft./lb. The cable loop reaches speeds up to 150 knots in about 2 seconds. The acceleration stroke (distance in which shuttle-engaging speed is reached) is 175 ft.



The tester is capable of simulating deadloads of 60,000 lb., 50,000 lb., and 30,000 lb. by changing the capstan rings. An 18,000-lb. arrestment is simulated by releasing the clutch just before the shuttle hook engages the arresting-gear cross-deck pendant.

The desired engaging speed level is obtained by selecting the proper initial flywheel speed.

#### Capstans and Bearings

The capstan, a drum around which the cable is wound, consists of two sets of split rings bolted to a hub. Since multiwrapped capstans are essentially unidirectional drives, a set of cable retainers (guides) is placed around the capstan to provide bi-directional capability to the AGT-1 for retraction. The capstan and shaft are supported by two hydrostatic fluid film bearings supplied with oil from a lube system whose fluid-flow capacity is 90 gallons a minute at 2,000 p.s.i. This lube system has a sump-pump unit, a heat exchanger, a lube pump, and an emergency lube system.

#### Flywheel

The 16,000-lb., 7½-foot-diameter by 7-inch-thick flywheel is supported by two hydrodynamic fluid film

bearings. The flywheel bearings also have an emergency lube system. During retraction, the flywheel is driven by a gas-turbine engine through a gear box, which reduces engine speed from 14,000 to 2,300 r.p.m.

#### Malfunctions and AGT-1 Protection

Low tension in the arresting-gear pendant, low hydraulic pressure in the arresting-gear cylinder, improper clutch pressure on the AGT-1, electrical-power loss, and an excessive shuttle stroke are dangerous system malfunctions. These are sensed by the solid-state control system which automatically provides the necessary emergency action.

If the arresting gear fails, the AGT-1 stops automatically by (1) releasing the clutch; (2) applying the capstan brake; and (3) engaging the deck-mounted emergency arrester (a set of two high-energy-absorbing annealed stainless-steel cables). A concrete-block barricade at the end of the shuttle track protects the capstan-flywheel drive assembly.

Any malfunction in the control system is easily repaired and serviced merely by replacing the plug-in modules. ☆

**LOCKHEED-CALIFORNIA COMPANY**

A DIVISION OF LOCKHEED AIRCRAFT CORPORATION  
BURBANK, CALIFORNIA 91503

April 1, 1970

Mr. G. C. McIntosh  
All American Engineering Company  
P.O. Box 1247  
801 S. Madison Street  
Wilmington, Delaware 19899

Dear Sir:

The following information is in response to your request dated  
12 March 1970 regarding the L-1011 airplane:

Design Landing Weight	348,000 Lb.
Design Takeoff Weight	409,000 Lb.
Landing Speed (1.3V <sub>s</sub> )	138 Knots
Takeoff Speed (V Lift Off, Hot Day)	152 Knots

Very truly yours,

LOCKHEED-CALIFORNIA COMPANY

  
R. H. Hopp  
Chief Engineer  
Commercial Engineering Advanced Design

RHH:ms

LOOK TO LOCKHEED FOR LEADERSHIP

**DOUGLAS AIRCRAFT COMPANY**

3855 Lakewood Boulevard Long Beach, California 90801

C1-25-2579  
24 March 1970

Mr. G. C. McIntosh  
Senior Project Engineer  
ALL AMERICAN ENGINEERING COMPANY  
P.O. Box 1247  
801 S. Madison Street  
Wilmington, Delaware 19899

Dear Mr. McIntosh:

In response to your letter of 12 March, we are pleased to provide you the following DC-10 data:

	Series 10	Series 20	Series 30
a. Landing Weight (Lbs.)	347,800	395,000	403,000
b. Maximum T.O. Weight (Lbs.)	410,000	515,000	555,000
c. Landing Speed - Touchdown with 50° flaps (Knots)	131	139	140
d. T.O. Speed - Liftoff Sea Level, 84° Day (Knots)	154	174	181

Attached is a copy of Report DAC-67803, DC-10 "Airplane Characteristics-Airport Planning," revised 14 November 1969. This document is currently being revised to reflect the Series 20 and 30 higher gross weights provided above.

If you desire future revisions to this DC-10 Airplane Characteristics book, please return the post card provided for your convenience in the front of the document.

This DC-10 data should be treated as preliminary in that changes will undoubtedly occur on the DC-10 as final specifications are negotiated.

This document provides general information for airport planning. Specific operational requirements of the aircraft are established by the airlines operating into the airport under consideration.

MCDONNELL DOUGLAS  
CORPORATION

C1-25-2579  
Page 2

We are certainly interested in the evaluation of military and commercial aircraft arresting systems. Consequently, we would appreciate receiving any data that may be available.

Please advise if you desire any further information.

Sincerely,

  
W. E. Parsons, Chief  
Airport/Aircraft Compatibility Engineer  
Advanced Design, Commercial Systems  
DOUGLAS AIRCRAFT COMPANY

RL0:th

Encl.

THE **BOEING** COMPANY

COMMERCIAL AIRPLANE DIVISION

SUPERSONIC TRANSPORT BRANCH • P. O. BOX 3733 • SEATTLE, WASHINGTON 98124

April 27, 1970

9-8150-0-12

Mr. G. C. McIntosh  
Sr. Project Engineer  
All American Engineering Company  
P. O. Box 1247  
801 S. Madison Street  
Wilmington, Delaware 19899

Dear Mr. McIntosh:


Your letter of March 12, requested takeoff and landing data on the Boeing Supersonic Transport and the 747. This information is shown below for the current 747 and for the 747B which is planned for production early in 1972. SST figures are for the current 298 passenger version of the production airplane. Configuration definition is scheduled for mid-1971, therefore the SST numbers are subject to change.

	<u>747</u>	<u>747B</u>	<u>Production SST</u>
Maximum Ldg. Weight, lbs.	564,000	564,000	460,000
Maximum Ramp Weight, lbs.	713,000	778,000	750,000
Velocity at touchdown, knots-EAS (Standard day)	138	138	151
Velocity at liftoff, knots-EAS (Standard + 15° C day)	169	178	197

Please contact the undersigned if additional SST information is desired.

Very truly yours,

THE BOEING COMPANY  
Commercial Airplane Group  
Supersonic Transport Division

  
P. L. Peoples  
Project Engineer  
Operations and Economics

5 March 1970

Hercules Powder Co.  
9th & Market Streets  
Wilmington, Del. 19801

Gentlemen:

We are currently under contract with the Edwards Air Force Base for a design study which in part calls for a study of different means of propelling a wheeled vehicle down a runway. The thrust requirement varies from 43,086 to 217,260 pounds per event; 30 to 40 events per month are required. The three prime candidates for the propulsion means are a catapult, turbojet engine car and a rocket propelled car.

We are, therefore, interested in obtaining both technical and cost data on the rocket or rockets that you would recommend to meet this requirement.

Please contact the undersigned if there are any questions.

Very truly yours,

ALL AMERICAN ENGINEERING COMPANY

G. C. McIntosh  
Sr. Project Engineer

GCM:dlb

5 March 1970

Thiokol Chemical Corporation  
Trenton  
New Jersey 08608

Gentlemen:

We are currently under contract with the Edwards Air Force Base for a design study which in part calls for a study of different means of propelling a wheeled vehicle down a runway. The thrust requirement varies from 43,086 to 217,260 pounds per event; 30 to 40 events per month are required. The three prime candidates for the propulsion means are a catapult, turbojet engine car and a rocket propelled car.

We are, therefore, interested in obtaining both technical and cost data on the rocket or rockets that you would recommend to meet this requirement.

Please contact the undersigned if there are any questions.

Very truly yours,

ALL AMERICAN ENGINEERING COMPANY

G. C. McIntosh  
Sr. Project Engineer

GCM:dlb

5 March 1970

Aerojet General Corporation  
Sacramento  
California 95813

Gentlemen:

We are currently under contract with the Edwards Air Force Base for a design study which in part calls for a study of different means of propelling a wheeled vehicle down a runway. The thrust requirement varies from 43,086 to 217,260 pounds per event; 30 to 40 events per month are required. The three prime candidates for the propulsion means are a catapult, turbojet engine car and a rocket propelled car.

We are, therefore, interested in obtaining both technical and cost data on the rocket or rockets that you would recommend to meet this requirement.

Please contact the undersigned if there are any questions.

Very truly yours,

ALL AMERICAN ENGINEERING COMPANY

G. C. McIntosh  
Sr. Project Engineer

GCM:dlb



TELEPHONE  
301-398-3000

*Thiokol*  
CHEMICAL CORPORATION  
ELKTON DIVISION  
ELKTON, MARYLAND 21921

TWX  
301-398-3914

March 25, 1970

All American Engineering Co.  
P. O. Box 1247  
Wilmington, Delaware 19899

Attention: Mr. G. C. McIntosh  
Senior Project Engineer

Subject: Edwards AFB Jet/Rocket Car

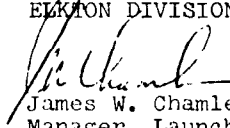
Gentlemen:

Thank you for considering Thiokol for your propulsion needs. However, we find that solid rocket motors would not be economically feasible for the subject program in comparison with surplus jet engines.

If we may be of further assistance, please contact us.

Very truly yours,

THIOKOL CHEMICAL CORPORATION  
ELKTON DIVISION

  
James W. Chamlee  
Manager, Launch & Escape System

JWC:cl



## HERCULES INCORPORATED

EXPLOSIVES & CHEMICAL PROPULSION DEPARTMENT      CHEMICAL PROPULSION DIVISION  
P. O. BOX 98, MAGNA, UTAH 84044      TELEPHONE: 297-5911  
21 April 1970

IN REPLY  
REFER TO: MISC/25/1-1682

All American Engineering Company  
P. O. Box 1247  
801 S. Madison Street  
Wilmington, Delaware 19899

Attention: G. C. McIntosh

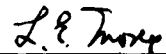
Gentlemen:

Responding to your letter of March 5, 1970, a tabulation of data on rocket motors which may suit your application is attached. All motors are capable of being produced without large start-up costs with one exception, the second motor listed.

From the data provided in your letter, it would appear that the turbojet engine, clustered as may be required for each mission, would be the most cost effective approach. As an alternate possibility, development of a suitably sized test weight rocket motor capable of cartridge loading and requiring little refurbishment after firing may prove to be attractive.

Do not hesitate to call G. I. Anderson at the Bacchus Works, Magna, Utah (801/297-5911 extension 2392) if we may be of further assistance.

Very truly yours,

  
\_\_\_\_\_  
L. E. Morey, Manager  
Advanced Studies

LEM:GIAnderson:drf  
Attachment

# ROCKET MOTOR PERFORMANCE QUESTIONNAIRE

<u>*Average Thrust(lb)</u>	<u>Burn Time(sec)</u>	<u>Motor Weight(lb)</u>	<u>Nominal Diameter</u>	<u>Thrust Time Relationship</u>	<u>Rough Order Unit Cost</u>	<u>Production Status</u>
17,600	57.0	4,232	38"	Relatively Flat	\$150,000	In Production
21,500	33.0	2,785	30"	Relatively Flat	85,000	In Production
30,900	80.0	9,550	54"	Regressive	180,000	Standby
32,750	59.0	8,458	54"	Regressive	150,000	Tooling not available Excess motors may become available
36,000	1.5	448	12.5"	Flat	13,000	Standby
60,460	4.3	1,830	18"	Slightly Progressive	35,000	Standby
64,010	67.2	16,877	74"	Relatively Flat	250,000	In Production
117,420	3.1	2,907	23"	Flat	40,000	Standby
121,000	2	1,230	29"	Regressive	45,000	In Production
157,800	65.0	42,150	74"	Slightly Progressive	250,000	In Production
585,000	1.5	4,800	47"	Regressive	75,000	In Production

\*Vacuum Thrust - Sea level thrusts slightly lower

# Bethlehem Steel Corporation

DISTRICT SALES OFFICE 1058 SUBURBAN STATION BUILDING

PHILADELPHIA, PA. 19103

N. L. FIMPLE  
MANAGER OF SALES  
W. J. GESNER  
G. W. MCALLIP  
ASSISTANT MANAGERS OF SALES  
J. R. WILSON  
CONTRACTING MANAGER



-15

PHONE 561-1100  
AREA CODE 215

March 26, 1970

All American Engineering Co.  
Box C - Union Station  
Wilmington, DE 19805

Attention: Mr. James E. Cannon, P.A.

Gentlemen:

Subject: Inquiry #11053

The following quotation is furnished in reply to your subject inquiry dated 3-5-70 covering a special zee section to be made in accordance with drawing submitted:

This special 8" zee section is to be furnished in accordance with design shown on our Drawing ER-17733.

Price is f.o.b. our producing mill at South San Francisco, California based on furnishing hot rolled material in minimum 177 net ten lots per rolling is 10.20¢ per lb. if section is produced to Specification C-1020.

The above price is based upon allowable variation in ordered quantities as follows:

You are to accept excess of the ordered quantity in the amount of 10% and accept 10% shorts down to 12 ft.

Any applicable extras for chemistry, specification, length tolerances other than shown on Print ER-17733, packaging, loading, marking, stamping, etc., will be in addition to the above named price, and are as shown in our Extra List, Section M1 dated March 1, 1970 attached or subject to negotiation.

Upon receipt of an order, we will provide special rolls and accessories to be used in producing this section in accordance with the mutually approved drawing. To cover cost of special rolls and accessories, we will charge your account the sum of \$37,171.00 to be invoiced when the rolls and accessories are completed, and to be paid by you subject to terms of net cash in thirty (30) days.

(continued.....)

*Bethlehem Steel Corporation*

All American Engineering Co.

-2-

March 26, 1970

Attention: Mr. James E. Cannon, P.A.

Custody and title to such rolls and accessories shall at all times remain in Bethlehem Steel Corporation.

During the period of five years immediately following the date of the order for such rolls and accessories, we will refund to you the sum of \$2.00 per net ton on account of all shipments of the sections produced from such rolls and accessories, until the total of such refund shall have equalled the payment made on such rolls and accessories.

After the period of five years, no refunds will be made on account of such payment, even though the total of all refunds shall be less than the payment made on special rolls and accessories, unless we, in our sole discretion, shall from time to time determine otherwise.

If in our opinion after the expiration of said period of five years the tonnage ordered by you of the section produced from such rolls and accessories does not justify our retaining such rolls, we may, after thirty (30) days written notice to you, scrap or use such rolls and accessories as we shall determine.

If you place an order for the above-mentioned rolls and accessories, it is understood that such order will constitute acceptance of the foregoing provisions. It will require approximately 36 weeks after entry of order to prepare the necessary rolls and equipment to produce this section. Attached are three (3) copies of our Drawing ER-17733 showing the section we propose producing. You are requested to signify approval on one copy of the print and return to us for our files.

The above named prices are for acceptance within 30 days of date, the above price, including extras and other charges, shall be adjusted to our price in effect at time of shipment.

This quotation is subject to the Terms and Conditions of Sale BSC Com. 1a (Rev. E 12-65) attached hereto and made a part hereof.

Please note our facilities are not qualified under MIL-Q9858A.

MIL-Q9858A does not apply to rolled products such as shapes. It applies only to finished products such as fabrication.

(continued.....)

*Bethlehem Steel Corporation*

All American Engineering Co.

-3-

March 26, 1970

Attention: Mr. James E. Cannon, P.A.

Our standard terms of payment for this product are 30-1/2-10.

We thank you for the opportunity to quote and look forward to receiving your order. Please refer to the date of this quotation when ordering.

Very truly yours,

BETHLEHEM STEEL CORPORATION

N. L. Fimple, Manager of Sales

By: 

DWHunt/bjf

Attachments

## GENERAL

## TERMS AND CONDITIONS OF SALE

All proposals, negotiations and representations, if any, regarding this transaction and made prior to the date of this quotation or proposal are merged herein.

**PRICES**—All prices, whether herein named or heretofore quoted or proposed, shall be adjusted to the Seller's prices in effect at the time of shipment.

If transportation charges from point of origin of the shipment to a designated point are included in the prices herein named or heretofore quoted—

(a) any changes in such transportation charges shall be for the account of the Buyer;

(b) except as otherwise stated in the Seller's quotation, the Seller shall not be responsible for switching, spotting, handling, storage, demurrage or any other transportation or accessorial service, nor for any charges incurred therefor, unless such charges are included in the applicable tariff freight rate from shipping point to the designated point.

**TAXES**—Any taxes which the Seller may be required to pay or collect, under any existing or future law, upon or with respect to the sale, purchase, delivery, storage, processing, use or consumption of any of the material covered hereby, including taxes upon or measured by the receipts from the sale thereof, shall be for the account of the Buyer, who shall promptly pay the amount thereof to the Seller upon demand.

**DELAY**—The Seller shall be excused for any delay in performance due to acts of God, war, riot, embargoes, acts of civil or military authorities, fires, floods, accidents, quarantine restrictions, mill conditions, strikes, differences with workmen, delays in transportation, shortage of cars, fuel, labor or materials, or any circumstance or cause beyond the control of the Seller in the reasonable conduct of its business.

**INSPECTION**—The Buyer may inspect, or provide for inspection, at the place of manufacture. Such inspection shall be so conducted as not to interfere unreasonably with the manufacturer's operations, and consequent approval or rejection shall be made before shipment of the material. Notwithstanding the foregoing, if, upon receipt of such material by the Buyer, the same shall appear not to conform to any contract resulting from this quotation or proposal between the Buyer and the Seller, the Buyer shall immediately notify the Seller of such condition and afford the Seller a reasonable opportunity to inspect the material. No material shall be returned without the Seller's consent.

**EXCLUSION OF WARRANTIES**—THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR PURPOSE ARE EXCLUDED FROM ANY CONTRACT RESULTING FROM THIS QUOTATION OR PROPOSAL.

**BUYER'S REMEDIES**—If the material furnished to the Buyer shall fail to conform to any contract resulting from this quotation or proposal or to any express or implied warranty, the Seller shall replace such non-conforming material at the original point of delivery and shall furnish instructions for its disposition. Any transportation charges involved in such disposition shall be for the Seller's account.

The Buyer's exclusive and sole remedy on account or in respect of the furnishing of material that does not conform to any contract resulting from this quotation or proposal, or to any express or implied warranty, shall be to secure replacement thereof as aforesaid. The Seller shall not in any event be liable for the cost of any labor expended on any such material or for any special, direct, indirect, incidental or consequential damages to anyone by reason of the fact that such material does not conform to any contract resulting from this quotation or proposal or to any express or implied warranty.

**PERMISSIBLE VARIATIONS, STANDARDS AND TOLERANCES**—Except in the particulars specified by Buyer and expressly agreed to in writing by Seller, all material shall be produced in accordance with Seller's standard practices. All material, including that produced to meet an exact specification, shall be subject to tolerances and variations consistent with usages of the trade and regular mill practices concerning: dimension, weight, straightness, section, composition and mechanical properties; normal variations in surface, internal conditions and quality; deviations from tolerances and variations consistent with practical testing and inspection methods; and regular mill practices concerning over and under shipments.

**PATENTS**—The Seller shall indemnify the Buyer against any judgment for damages and costs which may be rendered against the Buyer in any suit brought on account of the alleged infringement of any United States patent by any product supplied by the Seller hereunder, unless made in accordance with materials, designs or specifications furnished or designated by the Buyer, in which case the Buyer shall indemnify the Seller against any judgment for damages and costs which may be rendered against the Seller in any suit brought on account of the alleged infringement of any United States patent by such product or by such materials, designs or specifications; provided that prompt written notice be given to the party from whom indemnity is sought at the bringing of the suit and that an opportunity be given such party to settle or defend it as that party may see fit and that every reasonable assistance in settling or defending it shall be rendered. Neither the Seller nor the Buyer shall in any event be liable to the other for special, indirect, incidental or consequential damages arising out of or resulting from infringement of patents.

**CREDIT APPROVAL**—Shipments, deliveries and performance of work shall at all times be subject to the approval of the Seller's Credit Department. The Seller may at any time decline to make any shipment or delivery or perform any work except upon receipt of payment or security or upon terms and conditions satisfactory to such Department.

**TERMS OF PAYMENT**—Subject to the provisions of CREDIT APPROVAL above, terms of payment are as shown in the accompanying quotation and shall be effective from date of invoice. A cash discount shall not be allowed on any transportation charges included in delivered prices.

**COMPLIANCE WITH LAWS**—The Seller intends to comply with all laws applicable to its performance of any contract resulting from this quotation or proposal.

**RENEGOTIATION**—The Seller assumes only such liability with respect to renegotiation of contracts or subcontracts to which it is a party as may be lawfully imposed upon the Seller under the provisions of any Renegotiation Act applicable to any contract resulting from this quotation or proposal.

**NON-WAIVER BY SELLER**—Waiver by the Seller of a breach of any of the terms and conditions of any contract resulting from this quotation or proposal shall not be construed as a waiver of any other breach.

**ACCEPTANCE OF PURCHASE ORDERS**—ANY PURCHASE ORDER PURSUANT TO THE ACCOMPANYING QUOTATION OR PROPOSAL SHALL NOT RESULT IN A CONTRACT UNTIL IT IS ACCEPTED AND ACKNOWLEDGED BY THE SELLER'S GENERAL SALES OFFICE AT BETHLEHEM, PENNSYLVANIA.

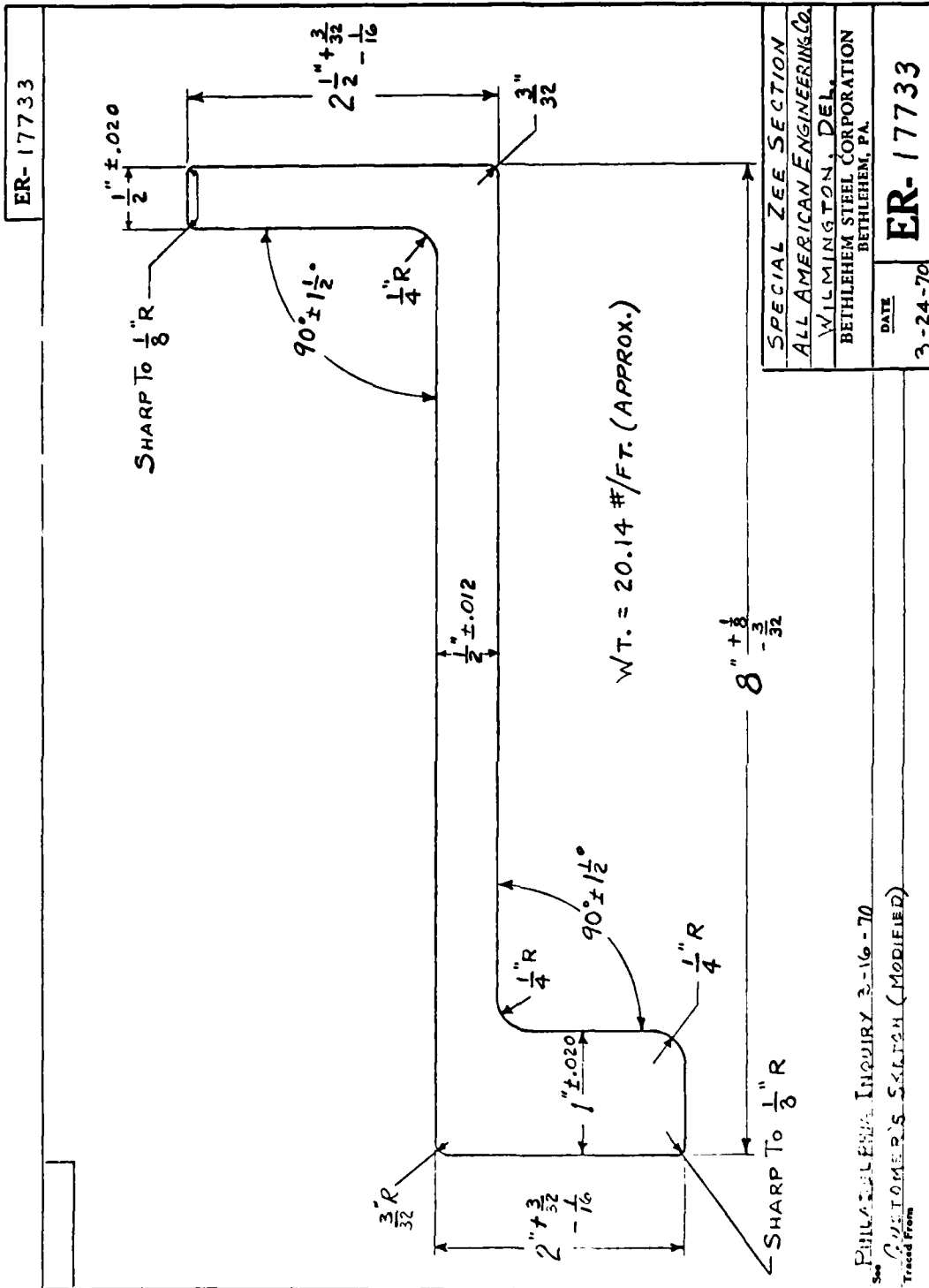


Figure 96. Special Zee Section Guide Rail



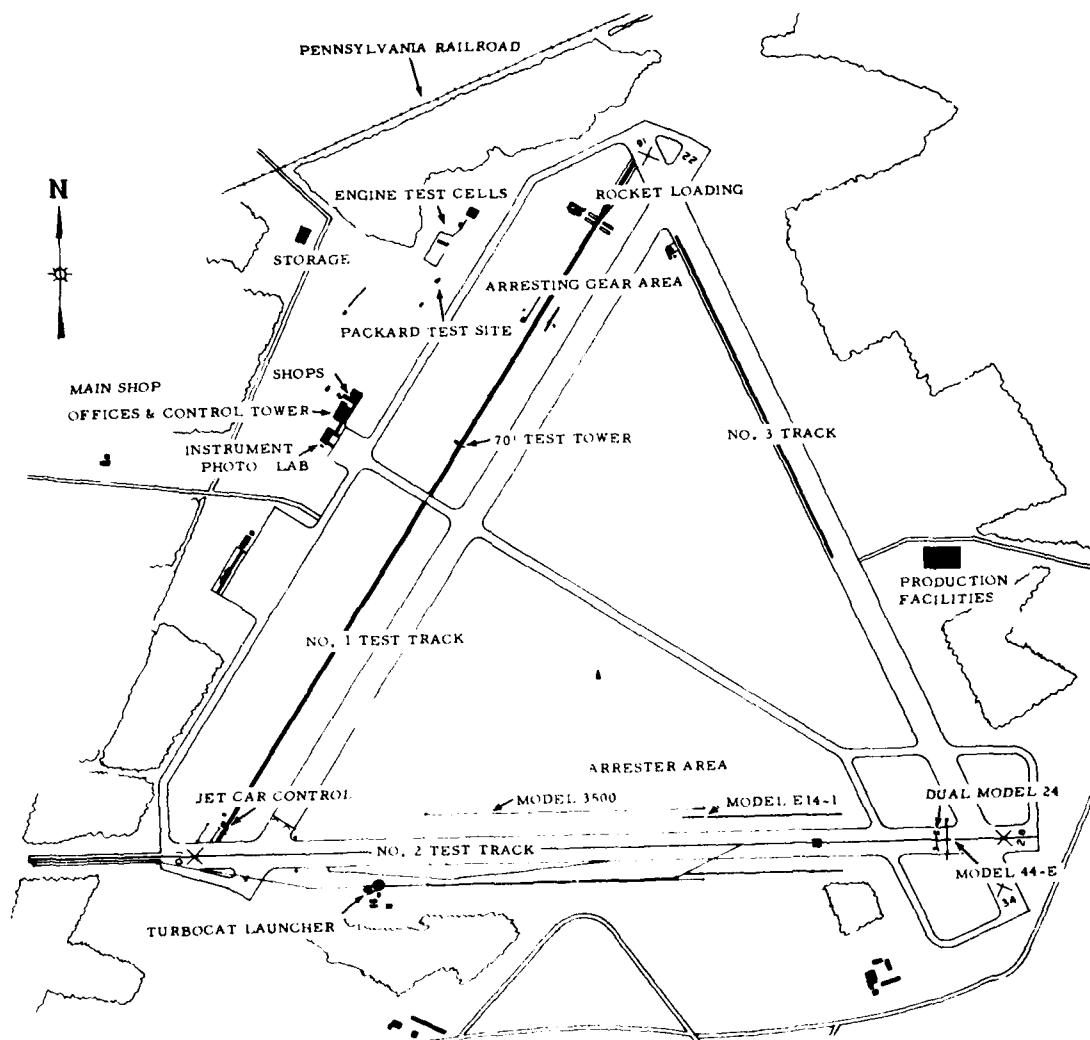


Figure 97. Georgetown Test Facility

## APPENDIX II

### NON-OPERATIONAL PROPULSION SYSTEMS

#### SOLID PROPELLANT JET, AIR EJECTOR, BURN SECONDARY AIR

This system consists of a solid propellant rocket engine properly shrouded for the inlet of air which combines with the rocket exhaust gases behind the rocket nozzle. In this region, fuel-rich exhaust gases are burned a second time to produce additional thrust. This is a system for producing a higher volume, low velocity jet than a rocket alone. On a total energy basis when compared to a conventional rocket engine this system would result in a low weight, less expensive but bigger envelope propulsive device.

#### REACTION JET SYSTEMS, SOLID PROPELLANT, JATO

In this system of launching an aircraft or deadload vehicle the thrust of one or more solid propellant rocket engines is used as the source of power to assist the vehicles in the case of aircraft to take off in a shorter than normal ground roll distance. JATO units, either by themselves or added to a conventional jet car, can be ignited at the start of the take-off run or at any subsequent point during the acceleration run depending primarily on the end speed required. JATO units have been used operationally for many years by the Air Force, Navy, Marine Corps, and Coast Guard. They are also used operationally worldwide to launch recoverable target drones. Their reliability is high and so is their cost. Based primarily on their high cost as compared to, for example, the cost of JP4 or JP5 jet engine fuel, their use is not considered as a serious candidate for the proposed deadload propulsion system.

#### HOT WATER ROCKET, POWARO

This rocket device is manufactured in Switzerland and produces by ejecting steam from a nozzle. This system consists of an engine case with internal heating elements for raising the temperature and pressure of water contained therein. Gasoline and air are mixed and burned in a combustion cavity below the water. The rocket is triggered by moving a control plug located just forward of the exit nozzle which allows pressurized hot water to be released into the exhaust nozzle where it flashes into steam. Characteristics of rockets of this type which have been manufactured are a total impulse of 25,688 pounds per second, initial water pressure of 782 psi and a water volume of 66 gallons. The peak initial thrust is 8930 pounds which falls off to zero thrust in five seconds. A distinct advantage of the hot water rocket is in the matter of economics since it needs only water and gasoline supplied to it to be reusable. Elsewhere in this report it has been shown that nominally 611,000 pounds of thrust will eventually be required to propel a 750,000 pound test vehicle to a speed of 300 knots. Based on the same thrust-to-weight ratio and assuming that a hot water rocket would be capable of being scaled up directly, the hot water rocket to generate the same amount of thrust would require 5,325 gallons of water as compared to the 66 gallons contained in the existing version. The water required would weigh 48,250 pounds and the rocket would weigh  $48,250 \times 1,371/573 = 115,414$  pounds. In order to physically carry this amount of water a cylindrical tank six feet in diameter and 251.75 feet long would be required.

## PULLEY TOW, JET CAR TOWING

This system consists of an auxiliary thrust production tow vehicle or jet car, a rope and pulley system rigged in such a manner that the towing vehicle is moving at half the speed of the vehicle being towed and a braking system for stopping the tow vehicle and the launch cable that connects the two vehicles. This system is depicted schematically in Figure 98. The tow vehicle is initially located at a point one-half the distance to the end of the runway. A launch cable extends from the tow vehicle to a shuttle at the battery position. The aircraft or other vehicle to be launched would be connected to the shuttle by a bridle that is automatically disengaged from the vehicle at the end of the accelerating stroke. In this system the shuttle is held captive in a flush mounted track which extends the length of the runway and is capable of resisting lateral and vertical loading on the shuttle. At the tow vehicle the launch cable passes around a pulley or sheave assembly and is, in turn, anchored to an energy absorbing cable arresting installation. During the acceleration stroke the cable arrester is locked and the launch cable effectively fixed. This results in a 2 to 1 acceleration in the vehicle to be launched as the tow vehicle moved toward the far end of the runway. As the end of the launch path is approached, the vehicle to be launched will be immediately behind the vehicle. At this point the thrust of the accelerating vehicle is removed which causes this vehicle to decelerate. The tow cable becomes slack and the test vehicle automatically disengages from the shuttle. The jet car continues into the decelerating area causing the tow cable and shuttle to contact the rear of the jet car and lock on as the cable stretches to full length between jet car and cable arrester. The energy absorbing cable arrester has been released at this point and is free to rotate as a rotary hydraulic braking system. Tape stored on the cable arrester drum and attached to the end of the launch cable unreels as the jet car is brought to a controlled stop. When the jet car stops, the shuttle at the rear of the car is engaged by a retrieval system located in the shuttle track. The shuttle with the jet car locked on is drawn back to its starting position. When it passes the mid-way point, the jet car detaches and remains at this location for the next launch. During the retrieval process the cable arrester is also driven backwards to rewind the tape stored on its drum.

## GAS TURBINE COMPRESSOR, PISTON/CYLINDER BURNER

A catapult system designated as the "Internal Combustion Catapult Power Plant" was designed and built by Reaction Motors Division of Thiokol Chemical Corporation under several Navy Department Contracts. A prototype labeled the C-14 catapult was installed at the Naval Air Test Facility, Lakehurst, N.J., and underwent development and reliability testing during the early 1960's. The system was intended to replace C-13 steam catapults which were proposed for nuclear powered aircraft carriers since the new carriers could not efficiently supply the relatively high pressure steam required for the steam catapults. The ICCP catapult system consists of conventional steam catapult tubes, pistons and interconnected shuttle, and the water brake. The propulsion system used JP5 jet engine fuel, compressed air, and water instead of steam as is the case with the C-13 steam catapults. As designed, air was compressed by two steam tur-

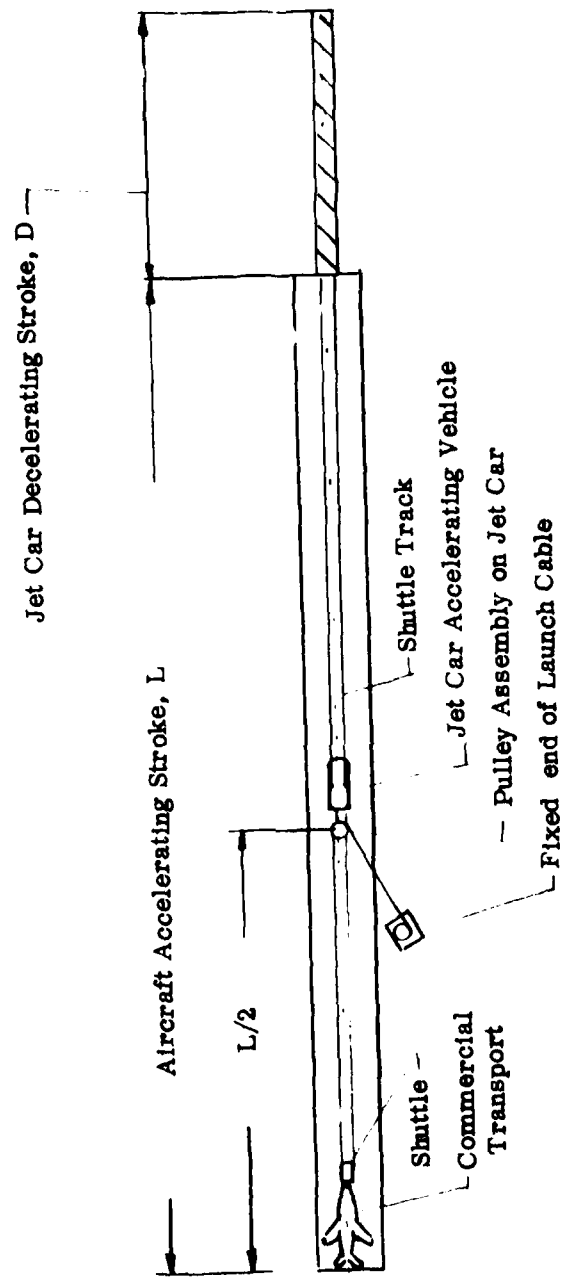


Figure 98. Pulley Tow Launch System

bines with their necessary auxiliary equipment and then stored in an air receiver prior to being used in the combustion process. During a launch cycle air, JP5 fuel, and water flow into the combustor head, are mixed and then ignited. The burning mixture then travels down the combustor where it is controlled by water spraying in from three water ejectors. The water when in contact with the burning gases flashes into steam. The mixture of steam and gas then acts on the phases of the pistons in the launch tubes, forces them down the tubes and then into the water brakes. A servo control valve controls the air, fuel, and water control valves so that theoretically a constant pressure is maintained in the catapult tubes during the launch stroke. This pressure may be generated and is determined by the weight of the aircraft and the end speed desired.

#### LARGE ELECTRIC MOTOR CONNECTED TO PPL

This system consists of one or more electric motors coupled to a capstan/cable friction drive through a clutch and a combining reducing gearbox. The tow cables, control system, shuttle, and shuttle arresting system would be similar to those of the gas turbine power catapult described previously.

#### CONVENTIONAL STEAM POWER PLANT, TURBINE, CAPSTAN DRIVEN CABLE

This system consists of a steam generating plant with suitable steam receivers and other necessary auxiliary equipment, one or more steam turbines with flow control valves, a combining reduction gearbox shaft connected to a capstan which in turn drives the launch or tow cable. The control shuttle and shuttle arrester systems would be similar or identical to those systems as described previously. Use of steam flow control valves is a recommended alternate for very high capacity clutches which would be a high cost maintenance item. This system is shown schematically in Figure 99.

#### STEAM TURBINE, CAPSTAN DRIVEN CABLE SYSTEM

This system uses steam as the prime source of power affecting a launching exercise. This system consists of the following components: an oil or gas fired steam generating unit with all of its accessories, steam receivers with adequate storage capacity, steam turbines with condensers with all of their accessories, a coupling, a clutch, a capstan or drum sized for the proper speed ratio, a cable compensator to provide sufficient slack side cable tension, sheaves, a cable or wire rope of the proper diameter, and a cable clamp device which connects the deadload to be accelerated to the tow cable. The entire system, when assembled, is controlled from one common control panel which would include monitoring instrumentation devices.

#### LINEAR INDUCTION MOTOR

A launch system presently under test by the U. S. Navy is an electric catapult.







The electropult equipment consists of two base components. The linear induction motor which converts electrical energy into mechanical work in the form suitable for producing a rapid acceleration of the deadload and the power generating station to supply the electrical energy needed to operate the linear motor.

The linear motor is similar, electrically, to the ordinary rotating induction motor except that it is flat instead of circular. The linear motor has a primary winding to which the electrical power is applied and a secondary winding in which currents are induced.

In any induction motor the primary windings may be either on the moving or the stationary member. In the "electropult" the primary windings are on the moving member which is the shuttle car or launch dolly. The secondary windings are on the stationary member, which is the track core or active track. The active track member is laid in a concrete trench so the core surface is level with that of the runway.

The active track has a total length of 1382 feet. The first 1000 feet of this track is designed for acceleration and the remainder for braking which is accomplished electrically by reversing the power connections.

In addition to the secondary core windings, the active track consists of the running rails, including upper rails to restrain the shuttle car from lifting during acceleration or deceleration, and a copper collector rail system for three phase power, tapped into a twin three phase, low reactance, bus bar feeder system.

The power generating station consists of a prime mover, normally an aircraft engine and a flywheel motor generator unit. The necessary control panels are also located in the power generating station. Auxilliary power is provided by a gasoline engine driven power plant.

The deadload is connected to the shuttle car with a bridle. When the shuttle car and deadload have reached the predetermined velocity, as determined from a calibration chart, power is cut off automatically. The method of obtaining the desired velocity, with various weights, is to vary the length of the acceleration stroke. Full tractive force is used for each launch.

The automatic cut-off is obtained by using local currents, which flow through the tap connections from the feeder bus bars to collector rails for control. The tap current rises as the shuttle car passes each of the taps. The current in the selected tap activates a relay at the power station thus interrupting the power. Reverse power is applied automatically after accelerating power is cut off, giving a very powerful deceleration force. The deceleration power is cut off automatically by means of an adjustable time element relay which has been set according to a chart. At the point of deceleration the deadload overruns the shuttle, sheds the bridle, and continues into the energy absorber.

## INTERNAL COMBUSTION OR STEAM ZIPPER CATAPULT

A proposed Zipper Catapult is shown in Figures 100, 101, and 102. The zipper catapult is a linearized engine which can be powered by internal combustion, steam, or compressed air. The power of expanding gas is transferred to a moving cam which drives the catapult shuttle. Catapult power can be increased by utilizing a quantity of cams and tandem. Conventional pistons and cylinders are replaced with chambers with moving walls. Thrust is developed by the difference in pressure on the forward and aft faces of the cam. As the cam moves, chamber source opposite the forward face of the cam is forced to retract into the body reducing the volume of the chambers. As the cam reaches its mid-point, steam is emitted or the compressed mixture of fuel and air is ignited to produce high pressure in the chambers on the aft face of the cam.

The construction is by a unit building block system of sections which are machined castings or weldments containing all of the parts necessary to form a section of twelve chambers. The catapult engine is thus made up of a number of these sections fastened together for the length required.

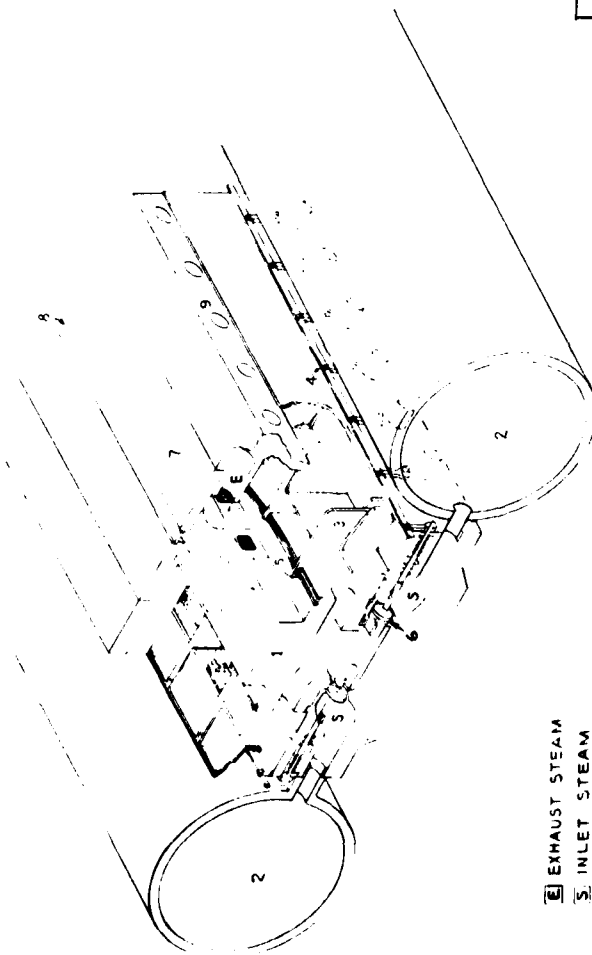
The internal combustion version of the zipper catapult is a linearized supercharged two cycle engine, utilizing cams and vanes in lieu of pistons and cylinders.

Air from the super charge manifold is allowed to enter the section chambers through ports in the shuttle at the low face of the cam. The rising face of the cam has no ports; therefore, the air in the chambers is compressed as the rising face of the cam passes. At approximately top dead center of the cam, fuel injection begins and ignition is applied. During passage of the trailing face of the cam, which also has no ports, burning continues until the excess of air is used up. After burning is complete, the hot gases are expanded until the exhaust ports in the low face of the cam are uncovered allowing the expanded gas to escape. As the chamber approaches supercharge pressure, intake ports are uncovered. With both intake and exhaust ports open, the chamber is scavenged of burned gas. As the cam continues to move, exhaust ports are closed and intake ports remain open to force a new charge of air into the chamber for the next cycle.

In order to start and stop the shuttle and cams at the end of the power and return strokes, a section such as that shown in Figure 102 is used at each end of the catapult. To start the stroke, the pilot air valve is opened admitting high pressure air to the chambers on the aft face of the cams. Sequential operation of these valves by pilot valves attached to moving walls accelerates the cam, shuttle, and aircraft until sufficient speed is attained for internal combustion to take over. At the end of the stroke, a similar section brakes the shuttle by compressing air and forcing it into a high pressure accumulator.

In the steam powered version of the zipper catapult, steam from the high pressure steam line enters the chambers through ports in the aft face of the cam



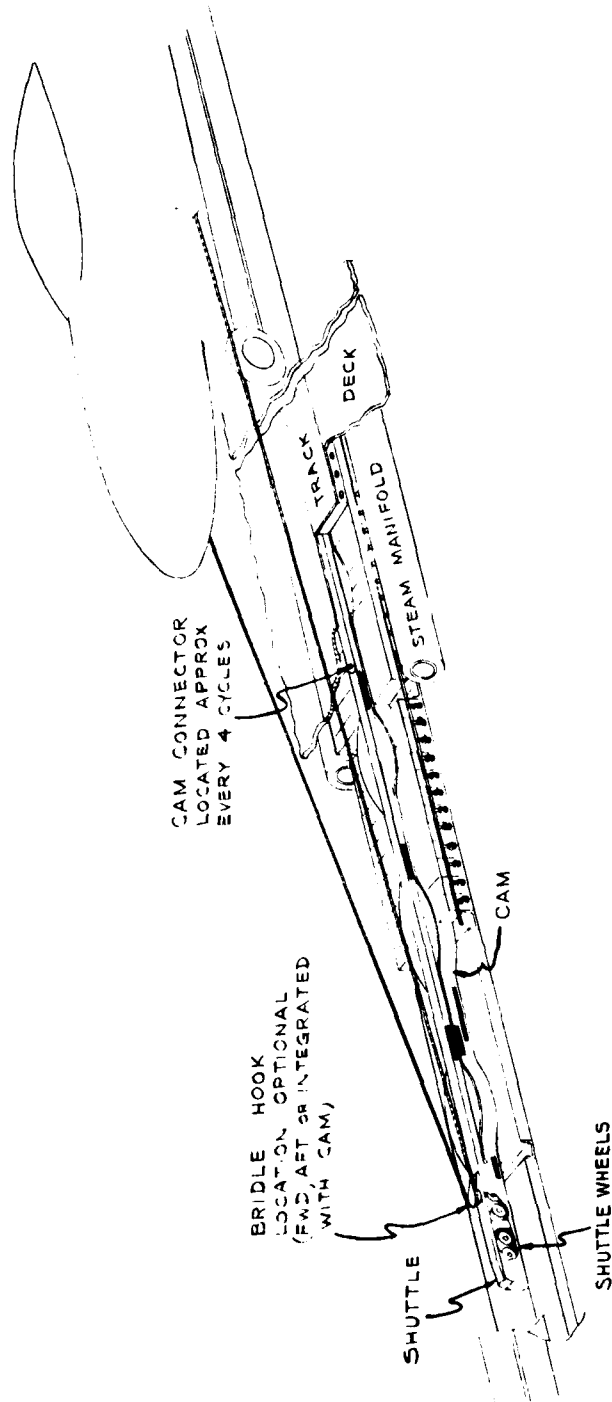


# INDEX

- 1 CAM
- 2 STEAM MANIFOLD
- 3 RETRACTABLE PANEL
- 4 VALVE LOCK MECH.
- 5 CAM FOLLOWER
- 6 INTAKE VALVE
- 7 TRACK
- 8 SEALING STRIP
- 9 EXHAUST PORTS

ALL AMERICAN ENGINEERING CO. WILMINGTON, DELAWARE, U.S.A.	
TITLE TYPICAL ENGINE CUTAWAY ZIPPER CATAPULT (STEAM)	
COOL. IDENT. NO. 96157	DATE B
DRAWING NO. 18SK578	
SCALE NONE	
REF. HEIGHT IN IN. FIG. 2, DRAW. 2-1581	

Figure 101. Typical Engine Cutaway Zipper Catapult (Steam)



ALL AMERICAN ENGINEERING CO. WILMINGTON, DELAWARE, U.S.A.		
TITLE		
ZIPPER CATAPULT SYSTEM LAUNCH CONFIGURATION FOR 75,000* TO 1,500,000* A/C		
CODE 1847 NO	SIZE	DRAWING NO
96157	B	18SK579
		REF: REPORT M-196
DATE		
NONE		

Figure 102. Zipper Catapult System Launch Configuration

section and is exhausted at the low face of the cam. This creates a differential pressure which drives each cam section. For maximum power, steam is admitted during the entire power stroke.

Braking of the shuttle is accomplished by a section at the end of the stroke, where pressure is applied to the exhaust ports and the pressure ports are opened to exhaust. This reverse porting is also used to drive the shuttle back to battery position.

#### REEVED CABLE, HYDRAULIC DRIVEN, HYDROPNEUMATIC ACCUMULATORS

This stored energy system consists of a hydraulic cylinder, a bank of hydro-pneumatic accumulators, a movable sheave connected to the cylinder piston, two fixed sheaves, and a guided movable sheave located on the runway to which the deadload towing bridle is attached as shown schematically in Figure 103. It requires a hydraulic reservoir, valves, and a pump as well as a brake for the movable sheave.

In operation the accumulator would have the proper precharge air pressure and hydraulic fluid. The deadload is moved to proper position and the holdback link and bridle attached. A valve is opened allowing pressurized hydraulic fluid to flow from the accumulator back to the hydraulic cylinder. This causes the piston to move along with all the components attached to it. The acceleration force breaks the holdback and propels the deadload along the runway. The brake provides the force necessary to stop all moving components at the end of the launch stroke. The hydraulic cylinder is now filled with hydraulic fluid at some comparatively low pressure. A second valve is opened and the retrieve engine engaged. The retrieve cable pulls the movable guided sheave along with the other sheaves to the battery position. This causes the hydraulic cylinder piston to move to the start position, forcing the hydraulic fluid from the cylinder to the reservoir. Both valves are then closed and fluid pumped into the hydraulic side of the accumulators making the system ready for the next launch.

#### COMPRESSED AIR, PISTON CYLINDER, PNEUMATIC ACCUMULATORS

This system is the same as that described above except that the medium for stored energy is compressed air instead of pneumatically-backed hydraulic fluid. The system would have the same basic components, less the fluid reservoir, and would operate in the same manner. Air compressors would charge the accumulators in preparation for the launch.

#### COMPRESSED AIR, PISTON CYLINDER, BURNER

A large diameter cylinder buried beneath the runway contains a free piston connected through a slot in the top of the cylinder to the deadload on the runway. The piston is propelled down the length of the cylinder by pressure derived from heated air. The air supply comes from gas powered axial flow free turbines driving fans which supply the air to the burner units capable of raising the air temperature to approximately 1000° F.

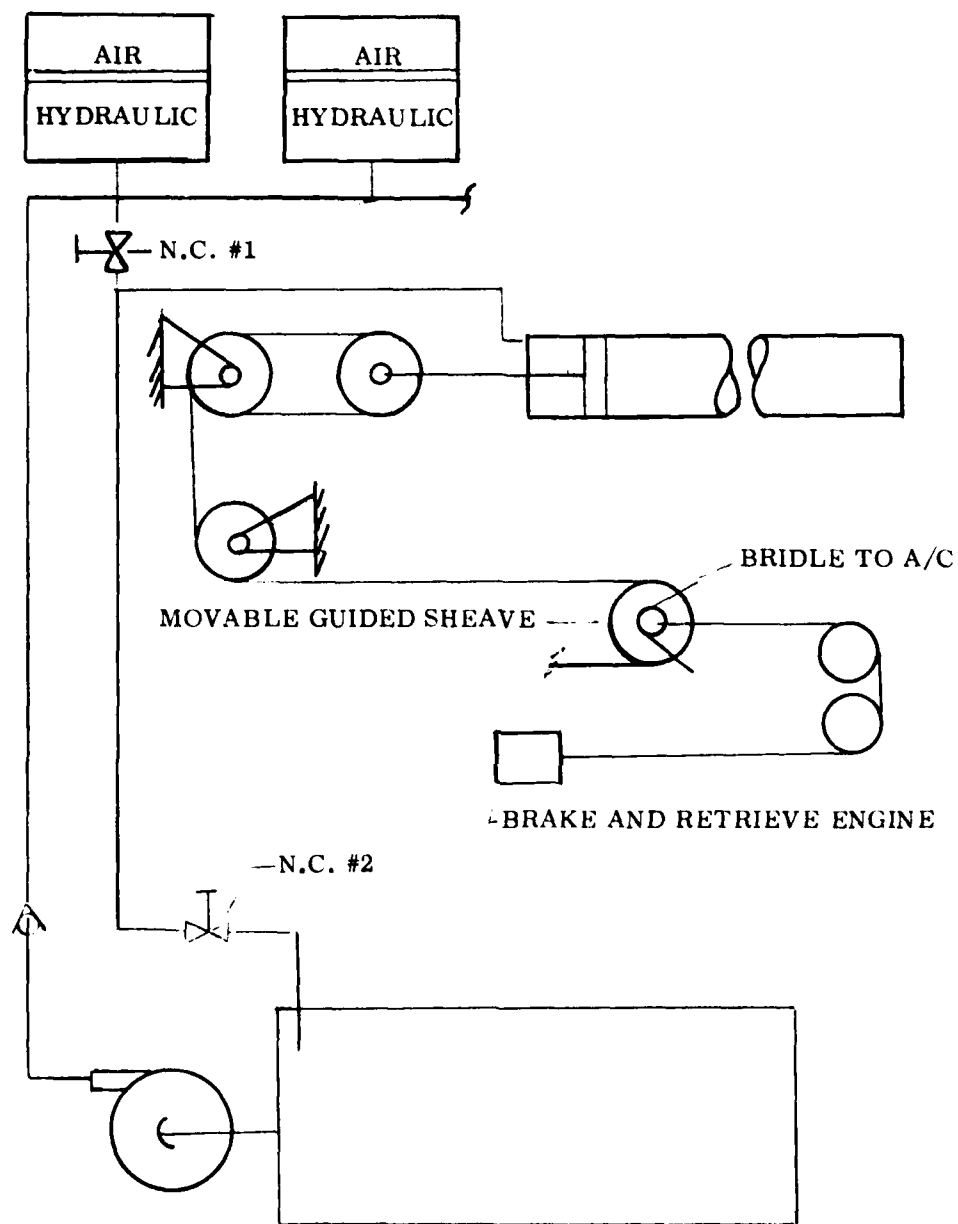


Figure 103. Reeved Cable, Hydraulically Driven  
Hydropneumatic Accumulators

## FLYWHEEL/CLUTCH CAPSTAN DRIVEN CABLE

This type stored energy system is comprised of a motor, clutch, flywheel, second clutch, brake, combining reducing gearbox and a capstan with its associated wire rope tow cable arranged in a loop configuration. Refer to Figure 1'4.

In operation clutch two is disengaged and the motor started. Clutch one is engaged and the flywheel is brought up to its operating speed after some period of acceleration time. The first clutch is disengaged uncoupling the motor from the flywheel making it a free rotating mass. When the deadload is ready for launch the second clutch is engaged coupling the flywheel to the capstan through the gearbox. The energy stored in the flywheel is translated as torque at the capstan radius into tow cable tension or tow force. This force breaks the hold-back link and accelerates the deadload to the desired velocity. A brake is used to stop the launch cable and rotating parts at the end of the launch cycle.

The basic system described above can have a number of configuration variations while maintaining the basic principle of stored energy in a rotating flywheel. The means of accelerating the flywheel can include electric motor, internal combustion engine or gas turbine. The method of converting the shaft torque to cable tension can include a cable wrapped capstan or a set of tape reels alternately reeling on and off during the launch cycle.

## WATER TURBINE-DRIVEN CABLE DRUM CATAPULT

This system consists of a water reservoir with provisions for the inlet of pressurized air, a water turbine, a cable drum drive assembly on the same shaft as the water turbine, a closed loop of launch cable, a bank of compressed air tanks together with the necessary motor/compressor unit, a motor/pump assembly for transfer of water and the necessary valving for control of both air and water shown schematically in Figure 105.

The launch force is provided in the form of launch cable tension by valving high pressure water into a water turbine directly connected to the cable-driving drum. High pressure water is produced by valving pressurized air from the accumulators to the water reservoir. The spent water is collected in a storage tank and later pumped back to the supply reservoir.

Alternate methods of pressurizing the water include the burning of a rocket grain and the heating and vaporizing of a liquid. This latter method would approach the steam turbine concept.

## STEAM CATAPULT (PISTON-CYLINDER DRIVE, HOT WATER ACCUMULATORS)

This system consists of two parallel tubes nominally 300 feet long, a control system, a shuttle to attach the deadload to the catapult and a source of steam and is shown schematically in Figure 105. Each tube contains a loose fitting



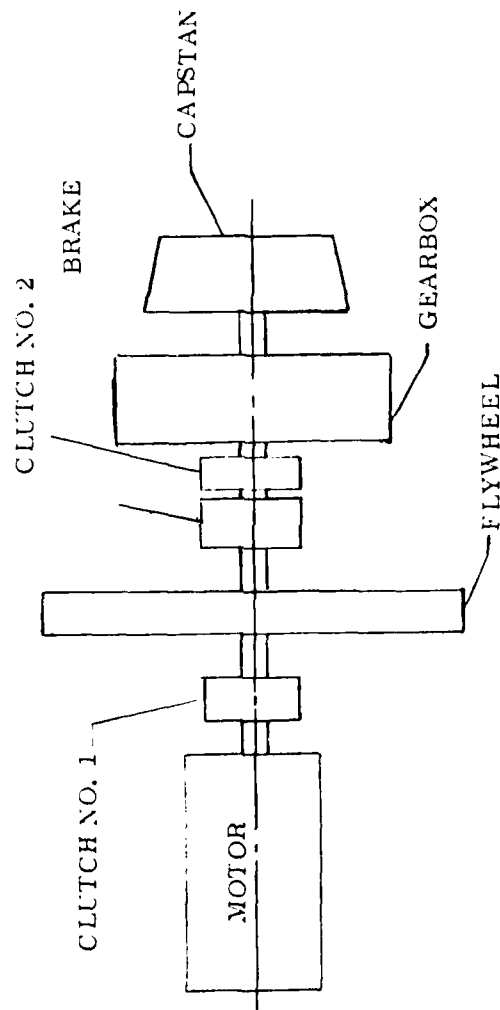
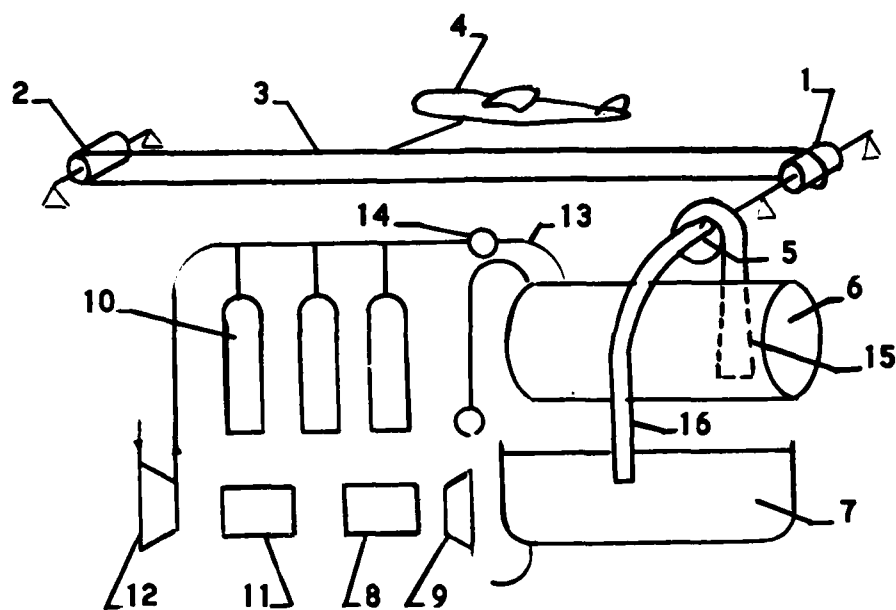


Figure 104. Flywheel/Clutch, Capstan Driven Catapult



- |                          |                              |
|--------------------------|------------------------------|
| 1. Battery roller        | 9. Pump                      |
| 2. Terminal roller       | 10. Compressed air container |
| 3. Continuous loop cable | 11. Electric motor           |
| 4. Aircraft              | 12. Compressor               |
| 5. Water turbine         | 13. Conduit                  |
| 6. Storage container     | 14. Valve                    |
| 7. Receiving container   | 15. Conduit                  |
| 8. Electric motor        | 16. Conduit                  |

Figure 105. Water Turbine

piston which is interconnected to the other through shuttle structure. The steam stored in receivers, upon demand, is expanded behind the pistons and accelerates these with the attached deadload and shuttle toward the terminal end of the tubes. The end velocity attained is a function of deadload weight and the steam pressure programmed for a specific launch. The pistons and shuttle must be returned to the starting or battery end of the catapult prior to the next launch cycle. This is accomplished by an auxiliary system.

This system is the conventional system installed on aircraft carriers in use by the U. S. Navy. The present stroke length of 300 feet is the design length for this application.

### APPENDIX III

#### EMPHASIS CURVES

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DECISIONS ANALYZER  
INDUSTRIAL EDUCATION INSTITUTE, BOSTON, MASS.

FORM DA-2  
 PROBLEM Rating Parameter  
 DATE \_\_\_\_\_ BY M. A. 264





SCOPE	ANALYSIS
<b>A</b> Rocket Car	A A A A A A A A A A A A A A A A A-0 <b>A</b>
<b>B</b> Steam Catapult	(B) (C) (D) (E) F G H I J K L M N O P Q R S T (3) <b>B</b>
<b>C</b> Flywheel Catapult	C C C C C C C C C C C C C C C (1) <b>C</b>
<b>D</b> CE Catapult	(D) (E) F G H I J K L M N O P Q R S T (2) <b>D</b>
<b>E</b> Jet Car	D D D D D D D D D D D D D D D (4) <b>E</b>
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DECISIONS ANALYZER FORM DA-1  
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SAFETY



▼  
analyzing decisions with the

▼  
emphasis  
curve  
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by Don Fuller, Director of Engineering Management, Industrial Education Institute, Boston, Massachusetts

PRINTED IN U.S.A.

### **Introduction**

The technique of analyzing decisions by the EMPHASIS CURVE was first introduced in management seminars conducted by me for the Industrial Education Institute and applied in my consultation work with the major companies of the United States and Western Europe to thousands of managerial and industrial problems. It was subsequently published in my texts, "ORGANIZING, PLANNING AND SCHEDULING FOR ENGINEERING OPERATIONS", "MANAGE OR BE MANAGED", and "GETTING TOP MILEAGE FROM YOUR DRAFTING AND DESIGN OPERATIONS". Since its publication it has been used on an ever-increasing scale as a basic tool of management in the analysis of decisions.

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### **THE MECHANICS OF THE TECHNIQUE**

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#### **the proper perspective**

A manager at any level is constantly being called upon to make decisions. When the decision involves no more than a simple choice between alternatives — a simple "this" or "that" — it may usually be arrived at with relative speed and accuracy. But far more often a decision must be based on a whole complex of circumstances or factors — each having a particular value for a given situation and quite another value in another situation.

The proper perspective is essential to clear thinking. One must be able to distinguish the big from the little, the important from the unimportant, the frozen from the liquid, the first from the last, and so on. When the scope of the problem is large and covers a large number of factors, gaining the proper perspective can be quite a difficult task.

#### **the scope**

Decisions analysis on the Emphasis Curve uses two forms identified as DA 1 and DA 2. Form DA 1 is our work sheet; DA 2 is a result sheet. The first column of DA 1 is the scope of the analysis.

The first step in analyzing a matter about which we wish to make a decision is to list the elements involved. This listing, called the scope, should be as complete as possible. When developing this listing, put down every factor which comes to mind and do not attempt any prejudgments as to what is or is not important. Any item that occurs to you as related, even remotely, to the problem is likely to occur to someone else, and you cannot, therefore, afford to ignore it. If it does turn out to be of minor or of no importance, the analysis will show this by the very low rank it will assign to the item.

All of the items listed on the scope will relate to our problem. Some will be of major importance, others of relatively minor importance. We know that in every complex situation there must be a certain amount of give and take as we try to arrive at a "fit", but though making concessions in one area may result in no more than slight annoyance or inconvenience, making them in another may have a far-reaching effect. Good *total* decisions are arrived at by an analysis of their lesser elements through the application of judgment based on facts, information, knowledge, experience, advice, and so on. This labor of analysis is coordinated and reduced by using the Emphasis Curve which helps to give the proper emphasis to the various factors so we can determine their relative importance.

#### analysis by comparison

The analysis is done by a series of comparisons, a comparison being the simplest and most direct of all measurements. As a matter of fact, all measurements involve a comparison with a standard, but a raw comparison calls for no measuring device: a thing is larger or smaller, lighter or heavier, smoother or rougher than another. The comparison is done on the TRI-ANGLE of form DA 1, which pairs each item on the scope with every other item. The choice is made by circling one or the other of each pair.

#### accumulating the results

The tabulation on our work sheet (DA 1) is completed by accumulating the number of times each item of the analysis has been selected and writing the result to the right. To assist in doing this a transparent overlay is provided. One has but to follow each line and count the number of circled items it intersects.

#### the ranking

The ranking is completed by transferring the results of the tabulation to the right-hand column of form DA 2. If, for example, item A has been circled 7 times, the letter A is written in one of the squares following the number 7. Two or more letters may follow the same number — meaning that, in relation to the whole problem they are relatively equal.

#### the results

The scope will now be rewritten in the results column of form DA 2 to show the order which has emerged from the analysis.

#### **the operation of the emphasis curve**

The operation of the Emphasis can be best learned by setting up a problem and working with an already prepared scope. Let us say that our problem is to rate a product from the standpoint of preparing a brochure to introduce it to the public. First we will select a "product" to be analyzed. Let us take for our product a small compact car, specifically a Volkswagen.

Each of us may have a different idea of what is meant by a brochure. We may also have a different picture of the purchasing public involved, but all that is asked at this point is that we have some kind of publication and some kind of public in mind. Perhaps you would like to consider yourself as being representative of the public you hope to reach. In such a case you can analyze in terms of your own preferences.

First we prepare our scope. It will be a short one of only ten factors. This does not necessarily mean that in our consideration of the problem only ten factors are possible, but we are going to limit ourselves to ten.

#### **a sample scope**

- a** Economy of operation
- b** Conservation of energy by the user
- c** Use span ( — obsolescence factor)
- d** Durability
- e** Comfort and convenience to the user
- f** Strength and rigidity
- g** Extra safety factors
- h** Ease of maintenance
- i** Esthetic considerations
- j** Gadgets of a non-functional nature

Before we can proceed, we must have a clear idea of the meaning of each item as it is related to our product. In other words, our terms must be defined. The definitions of terms would probably be quite different if the product we were analyzing were a lawnmower or a home deep-freeze.

- a** Economy of operation will refer to the running expenses of our car — such items as gas, oil, etc.
- b** In considering conservation of energy by the user, let us confine ourselves to ease of parking.
- c** Obsolescence will refer to the length of time we would be content to keep the car before feeling it should be replaced.
- d** Durability will refer to the upholstery, the finish and other non-mechanical items which should be expected to hold up well.
- e** As for comfort and convenience, you might think that a large car would certainly be more comfortable than a small one. But a woman driver might be very uncomfortable behind the wheel of a large car.
- f** Strength and rigidity will have reference to the chassis and framing.

**g** Of course, we expect every car to be safe, but are there any special safety features we would wish to emphasize in our brochure?

**h** Ease of maintenance will refer to repairs, minor adjustments and the like. Would they require the skill of an expert or could they be carried out by the owner with an assist from a maintenance manual? This may be very important where a foreign car is concerned.

**i** Esthetic considerations deal with visual refinement and attractiveness or "eye appeal".

**j** "Gadgets" refer to items of a non functional nature — nice to have, but not necessary to the operation of the car. A heater might not be considered a gadget, but a radio might well be.

#### **weighing the pairs**

Now comes the actual working out of the curve. This is done on the triangle of form DA-1 where each lettered item of the scope is compared with every other lettered item.

Let us take the first pair on the triangle: A-B. This pair covers the scope items: (a) Economy of operation; (b) Conservation of energy by the user.

We say to ourselves: "In preparing a brochure to introduce the Volkswagen to the public, which should receive the greater emphasis: A (— economy of operation) or B (— conservation of energy)? After making a choice, we CIRCLE either A or B and proceed to the next pair in line: A-C. Our choice here is between A (— economy of operation) and C (— use span). We do this for ALL pairs on the triangle.

#### **IMPORTANT**

It is vital that we actually make every comparison. Do not decide that some items are of outstanding importance and circle it straight across the line without bothering to make the actual INDIVIDUAL comparison. This would be the kind of pre-judgment we are most anxious to avoid. It is true that eventually the item may be circled all the way across, but only after we have compared it with the other items. You must make an individual decision for each pair. This is also a FORCED COMPARISON. You cannot decide that items are of equal importance and circle both or neither. Add factors mentally until one or the other of a close match has the edge. However, if you cannot separate them even after close analysis, it will be a matter of indifference which one you circle because the effect of your selection cannot possibly have a grave consequence on the final outcome when the items are that close together in value.

It is not a good idea to jump about on the triangle. It is far better to do the analysis line by line. In this way you always carry on with one item clearly defined in your mind as you introduce a new factor.

#### **tabulating the results**

Having completed the comparisons, our next step is to tabulate the results.

Using the overlay, we count each circled letter both vertically and horizontally. You will notice that the work-sheet (form DA 1) and the overlay are color-keyed: all A's are blue, all B's are black, etc.

#### CHECKING THE TABULATION

It is always a good idea to check the accuracy of your tabulation. This is done by adding the circled numbers which precede the letters in the right-hand column of the work-sheet. When there are ten items on the scope these should add up to 45 because there are 45 comparisons to be made on the triangle. As there is nothing magic about the number 10 and there may be more or less items on the scope, you will want to know how to find this check number easily. The formula is  $N(N-1)/2$ , with  $N$  representing the number of items on the scope. In other words, multiply the number of items on the scope by the next lower number and divide by 2. If the number of items on the scope is 7, you will multiply 7 by 6 ( $7-1$ ) and divide the result ( $42$ ) by 2 and your check number will be 21. There are 21 comparisons on a 7-item scope.

#### ranking the results

The process is continued by transferring the results of the analysis on form DA 1 to the "Rank" column of form DA 2 where the items of the scope will be ranked in relative importance from highest (circled the most times) to lowest (circled the least times or not at all).

If your ideas of what the public wants in a compact car are correct, you will, in the writing of your brochure, wish to lay great stress on the items that rank highest and less on the lower-ranking items.

If two or more items have the same "Rank", it means that in relation to all the items on the scope they are relatively equal.

#### the emphasis curve as a process

The development of the Emphasis Curve is, in a sense, mechanical, but so is any type of data processing. We may say it is mechanical but not automatic. The process relies heavily on the knowledge and the judgment that is brought into play in making the comparisons. In all matters which involve judgment there are no absolute rights and wrongs, only answers that are better or worse than others.

#### SOME IMPORTANT APPLICATIONS OF THE EMPHASIS CURVE TECHNIQUE

- 1 Establishing priorities
- 2 Isolating "headaches" and "roadblocks"
- 3 Rating personnel in developing "task forces"
- 4 Seeing if you and your subordinates are working at cross-purposes

- 5 The "management of change"
- 6 Checking the perspective of "delegates"
- 7 Discussing and clarifying performance reports
- 8 Balancing the equipment budget
- 9 Developing the "sequence" of a schedule
- 10 Establish the proper emphasis in advertising and promotional material
- 11 Organizing the executive workload
- 12 Taking out insurance against oversight

In each case the proper question must be asked and we must understand what the "Results" mean.

#### 1 PRIORITIES

**The Question:** Between item     and     which should be done first?

**The Result:** Jobs with the highest priority will be circled the largest number of times.

#### 2 "HEADACHES"

**The Question:** Between item     and     which is giving us the most trouble?

**The Result:** Jobs with a high rank are "troublemakers" and "roadblocks". It might be to your advantage to get them out of the way by finishing them — even though they have a low priority.

(The scope will be a listing of all personnel)

**The Question:** If I had to lose A or B, who would I hang on to as the more valuable man?

**The Result:** A listing of the personnel in the order of their value to your operation. Every effort should be made to assign routine work to the lower-ranking men, keeping the best men free and available for special tasks calling for real ability.

#### 4 "CROSS-PURPOSES"

Often people are working hard instead of smart — putting their best efforts in the wrong places. You and your subordinates should make out parallel analysis to see if they really have the same perspective on their job as you have.

**The Question:** Between item     and     which is the more important?

**The Result:** When you and your subordinates agree as to what is important and what is not, there is better coordination of effort and less friction. Marked deviations between his analysis of his job and yours call for discussions that can be very fruitful.

## 5 CHANGES

The greatest difficulty in the handling of changes is the degree of opposition to the change. The scope will be a list of changes you wish to make.

**Question:** Between item - and - which, because of expected opposition, will be the more difficult to put into force?

**The Result:** The most difficult changes to "sell" or implement will be at the top of the list, the easiest at the bottom. Obviously, you will start with the easiest and build on your successes.

## 6 DELEGATION

Obviously, your delegate must think as you do if he is to properly represent you rather than himself. To find out if his ideas vary widely from your own, you should make parallel analyses to spot divergencies.

## 7 PERFORMANCE

A performance report lists certain qualities and characteristics and "rates" a man on them. The value of these qualities will vary from job to job. "Decision-making" may be major in some jobs, minor in others. An analysis of job requirements can be very important. Then a parallel analysis is made of the man's strengths and weaknesses.

**Question:** Between item and which do you consider your stronger point as it relates to your performance in your present assignment?

**The Result:** You will be surprised how blind people can be to their own weaknesses.

## 8 BUDGETING

The scope will be a listing of all the equipment (or other expenditures) you would like to make if you had unlimited funds.

**Question:** Between item and , if I were forced to give up one or the other, which would I prefer to retain?

**The Result:** A priority listing based on preferences. When priced out, you will run out of available funds at some point. Anything on the list below this point can be acquired only by sacrificing something above the line or going outside the budget for additional funds.

## 9 SEQUENCE

The scope will be a listing of the individual operations or tasks on the schedule.

**Question:** Between item and which should be done first?

**Result:** The critical path of the operation, or the first raw network.

## 10 EMPHASIS IN PROMOTIONAL MATERIAL

This analysis has already been treated in the text as an example of the working out of the emphasis curve.



## 11 WORKLOAD

The scope will be a listing of all the items on your workload.

**Question:** Between item      and,      if I had to postpone one or the other, which could I least afford to postpone?

**Result:** A listing in the order in which work items really DEMAND your attention. It is obvious that, with a limited amount of time at your disposal, doing anything on the lower end of the list is always at the expense of things at the upper end. How many of the lesser items really demand your personal attention? Couldn't you delegate some if not all of them?

## 12 INSURANCE AGAINST OVERSIGHT

When you have established a sequence of operations and listed them in your results column on form DA 2, this will be the scope for an examination against oversight.

**Question:** Can I go directly from the first listed item to the second, or is there some intervening step or operation which is required?

These are only a few of the hundreds of possible applications of the Emphasis Curve to the analysis of decisions. It is the intention of the Industrial Education Institute to collect new applications and circulate them from time to time to users of the technique. If you, in your turn, develop a new application, I would be very interested in hearing about it.

Address all communications regarding the technique to:


DON FULLER, Director of Engineering Management  
Industrial Education Institute  
221 Columbus Ave.  
Boston, Massachusetts 02116

SCOPE	ANALYSIS
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RESULTS	NOTES	RANK
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MAXIMUM  
 ↑  
 MINIMUM


 DECISIONS ANALYZER  
 INDUSTRIAL EDUCATION INSTITUTE, BOSTON, MASS.

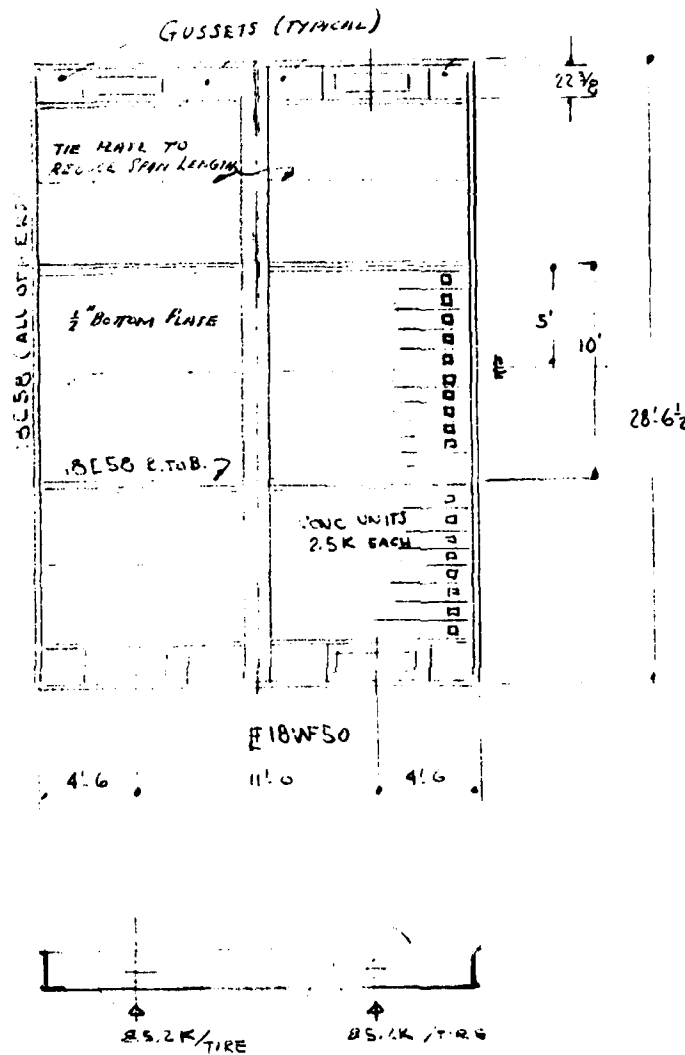
FORM DA 2  
 PROBLEM \_\_\_\_\_  
 DATE \_\_\_\_\_ BY \_\_\_\_\_

DECISIONS ANALYZER FORM DA-3  
INDUSTRIAL EDUCATION INSTITUTE BOSTON, MASS.

#### APPENDIX IV

#### PRELIMINARY STRESS ANALYSIS

# DEADLOAD MODULE L-00880



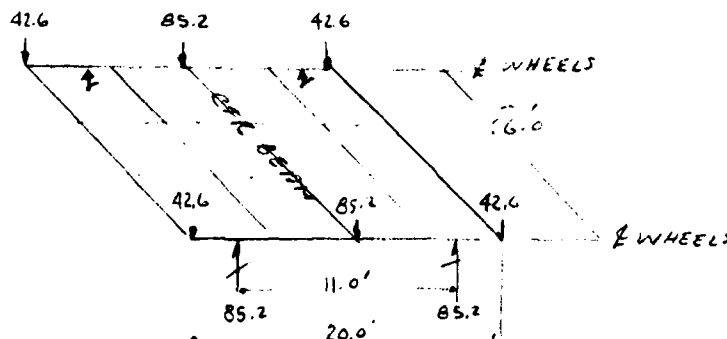
Wt. 30,400 MTY  
 170,400 full  
 2G Vertical  
 2G Transverse  
 2G Horizontal  
 Assume a 1.15 YLF  
 Mat'l. Stl  
 $F_{tu} = 55 \text{ ksi}$   
 $F_{ty} = 36 \text{ ksi}$

## Tire Loading

170,400 lb. x 2 1/4 tires = 85,200 lb. or 85.2 K each

# DEADLOAD L-00680

For 2G vertical Loading condition  
assumed load distribution shown shaded



## Center Beam (18 WF50)

Load, W

$$W = 2 \text{ G's} \times \frac{1}{2} \times 170,400 = 170,400 \text{ lbs. or } 170.4 \text{ kips}$$

Reaction,  $R_c$

$$R_c = W/2 = 85,200 \text{ lbs. or } 85.2 \text{ kip}$$

Moment, M

$$M = \frac{WL}{8} = \frac{170.4 \text{ K} \times 26.0 \text{ ft.}}{8} = 565.5 \text{ ft. kips}$$

Section Modulus Req'd.,  $Z_R$

$$Z_R = M/F_{tu} = \frac{565.5 \text{ ft. kips} \times 12 \text{ in./ft.} \times 1000 \text{ lb./kip}}{1.15 \text{ YLF} \times 36,000} = 163.9 \text{ in.}^3$$

$$Z_{\text{provided}} = 143.0 \text{ in.}^3 < Z_R$$

## Front & Rear Beam (18 C58)

Loading 50% of Ctr. Beam  $Z_{\text{req'd}} = 82 \text{ in.}^3$

$$Z_{\text{provided}} = 97.2 \text{ in.}^3 > 82 \text{ in.}^3$$

## Side Beams (2-18 C58)

Moment,  $M_{@R}$

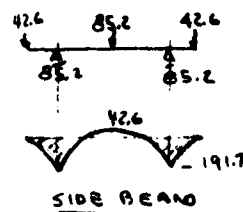
$$M_{\text{max}} = -42.6 \text{ k} \times 4.5 \text{ ft.} = -91.70 \text{ ft. kips}$$

$$M_{@Ctr} = -42.6 \text{ K} \times 10.0 \text{ ft.} + 85.2 \text{ K} \times 5.5 \text{ ft.} = +42.6 \text{ ft. kips}$$

Section Modulus, Req'd.,  $Z_R$

$$Z_R = M/F_{tu} = \frac{.29 \times 191.7}{1.15} = 55.6 \text{ in.}^3$$

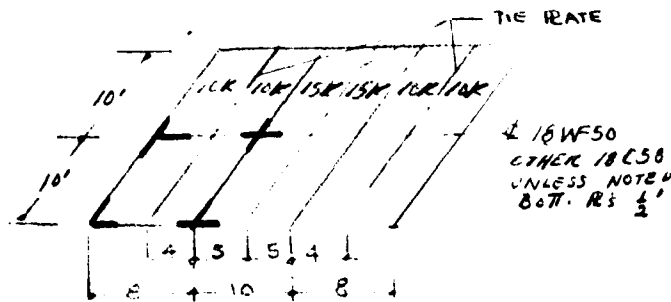
$$Z_{\text{provided}} = 2 \times 74.5 \text{ in.}^3 \gg Z_R$$



# DEADLOAD L-00680

For 2G horizontal loading condition

Consider the body as a frame and utilizing 12t of bottom plate as the effective beam member affixed to structural member.



Tie Plate required to break up span lengths

## Section Properties

	A	Y	AY	AY <sup>2</sup>	I <sub>o</sub>	C = 10 - $\bar{Y}$
	16.98	3.12	52.98	165.29	18.5	10 - 3.55 = 6.45in
	5.00	5.00	25.00	125.00	5.2	
	21.98	3.55	77.98	313.99		Z = $\frac{I_{cg}}{C} = 5.78 \text{ in.}^3$
			3.55 x 77.98 = -276.66			
			I <sub>cg</sub> = 37.33 in. <sup>4</sup>			

Consider front section (Ctr. 5' span as a fixed beam uniformly loaded

$$M_{@ \text{ Ctr}} = Wl/24 = 15 \times 5/24 = 3.125 \text{ ft. kip}$$

$$M_{@ \text{ End}} = Wl/12 = 15 \times 5/12 = 6.250 \text{ ft. kip}$$

Section Modulus Req'd, Z<sub>R</sub>

$$Z_R = 6.250 \text{ ft. kips} \times 12 \text{ in/ft} \times 1000 \text{ lb/Kx2G's/36,000 psi} \times 1.15 = 3.62 \text{ in.}^3 < 5.78 \text{ in.}^3$$

Consider 4' span

$$M_{@ \text{ Ctr}} = 4/5 \times 3.125 = 2.5 \text{ ft. kip}$$

$$M_{@ \text{ End}} = 4/5 \times 6.250 = 5.0 \text{ ft. kip}$$

Side Channel @ Ctr. Section

$$M_{\text{above}} = M_{\text{below}} = .5 \times 5.0 \text{ ft. kip} = 2.5 \text{ ft. kip}$$

Ctr. Channel @ Differential Span Lengths

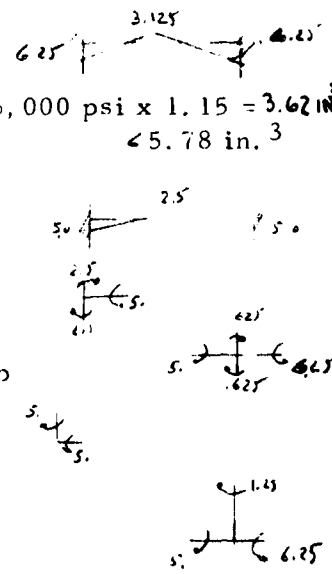
$$M_{\text{above}} = M_{\text{below}} = .5 \times (6.25 - 5.00) = 6.25 \text{ ft. kip}$$

Corner Section (Front)

$$M = 5.0 \text{ ft. kip}$$

Ctr. Section (Front) @ Span Length

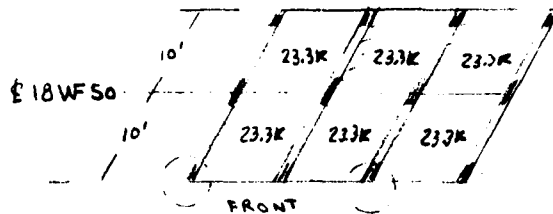
$$M = (6.25 - 5.00) = 1.25 \text{ ft. kip}$$





DEADLOAD L-00680

Traverse Loading Condition



Gusset zone to minimize span level and increase stiffness to handle end moments

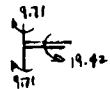
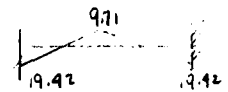
Moments

$$M_{\text{Ctr}} = 23.3 \text{ kip} \times 10 \text{ ft} / 24 = 9.71 \text{ ft. kip}$$

$$M_{\text{End}} = 23.3 \text{ kip} \times 10 \text{ ft} / 12 = 19.42 \text{ ft. kip}$$

The stiffness at corner beams controls the distribution of the moment and it is assumed the moment at corner rear and front beam is 25%  $M_{\text{End}}$  or 4.9 ft. kip and from previous analyses indicates it's very strong

At mid section the stiffness above & below Ctr ends are equal and  $\therefore$ , the distribution is 50% or 9.71 ft. kipsi

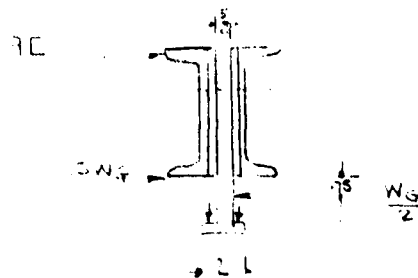


Maximum Stress,

$$= \frac{9.71 \text{ ft. kips} \times 12. \text{ in/ft.} \times 1000 \text{ lb. /kip} \times 2. \text{ G's}}{5.78} = 40,318 \text{ psi} > 36 \text{ kis}$$

Local reinforcement of plate would reduce stress and the 18W 50 is adequate by inspection

GUIDE L-00707



Mat'l. T<sub>1</sub> St.  
 $F_{tu} = 90 \text{ ksi}$   
 $F_{ty} = 70 \text{ ksi}$

Side load imposed on guide is based on an assumed load distribution on overall 2G's transverse loading reacted both by tires and guide.

Total Load,  $W$

$$W = 2 \text{ G's} \times 170,400 = 340,800 \text{ lb.}$$

Assumed Friction Resistance of 4 Tires

$$W_T = .5 \times 170,400 = 85,200 \text{ lb.}$$

Load imposed on 2 guides,  $W_G$

$$W_G = W - W_T = 255,600 \text{ lb.}$$

Bending on Guide Section  $38 \times .625$ ,  $f_b$

$$f_b = \frac{6 \times 255,600 \times .75}{2 \text{ guides} \times 38 \times .625^2}$$

$$38,743 \text{ psi}$$

Design Margin, DM

$$DM = \frac{90,000}{1.5 \text{ ULF} \times 38,743} - 1 = .55$$

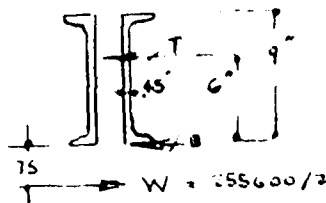
Uplift Load on Guides (Assume 1 guide)

$$f_t = 2 \text{ G's} \times 170,400 / (1) \text{ Guide} \times 10 \times .625 = 54,500 \text{ psi}$$

$$f_{baa} = 6 \times 85,200 \times .34 / 10 \times 1^2 = 17,381 \text{ psi}$$

# GUIDE L-00707

Effects of side load on channel supporting guide



$$B = 127,800 \times 6.75/6.00 = 143,775 \text{ lb.}$$

$$T = 127,800 \times .65/6.00 = \frac{15,975 \text{ lb. (bolt tension)}}{127,800 \text{ lb.}}$$

Bending of Channel,  $f_b$

$$f_b = \frac{6 \times 143,775 \text{ lb.} \times 6 \text{ in. moment arm}}{38 \text{ in. length} \times .45 \text{ in. (thickness)}} = 672,631 \text{ psi} \gg 55,000 \text{ psi}$$

NOTE: Gussets are required to stiffen section

Shear Load on Guide Bolt,  $P_s$

$$P_s = \frac{170,400 \text{ lb.} \times 2 \text{ G's}}{2 \text{ (double shear)} \times 2 \text{ units}} = 85,200 \text{ lb. (single shear load)}$$

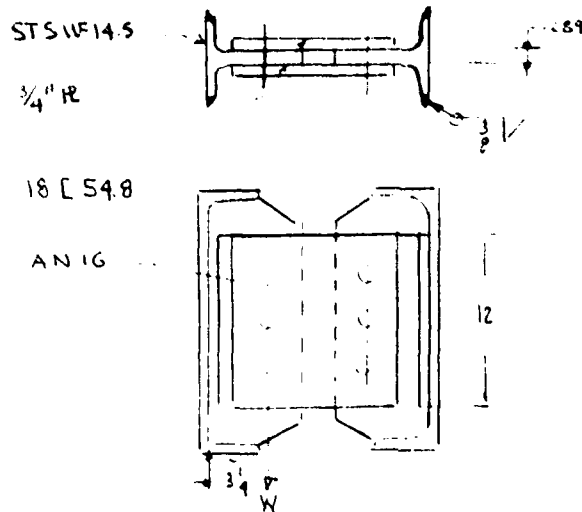
Recommend 1-1/2 in. bolt size minimum  $P_s$  rating of 150,000 lb.

Bearing Stress,  $f_{br}$

$$f_{br} = \frac{170,400 \text{ lb.} \times 2 \text{ G's}}{2 \text{ units} \times 1.5" \phi \times 2 (.45 + .38 + .38)} = 46,942 \text{ psi} < 65,000 \text{ psi}$$

\ fill plates

COUPLER ARRANGEMENT L-00670



Assume  $W = 170,400 \text{ lb.} \times 2 \text{ G's} \times 25\% = 85,200 \text{ lb.}$

Shear Stress in Weld,  $f_s$

$$f_s = W/2 \times .375 \times 16.00 = 8000 \text{ psi}$$

Bending Stress in Weld,  $f_b$

$$f_b = 3 \times 85,200 \text{ lb} \times 3.25 \text{ in.} \div 16^2 \text{ in} \times .375 = 8653 \text{ psi}$$

Bending Stress in Stem of Structural Tee,  $f_b$

$$f_b = 85,200 \text{ lb.} \times 2.75 \text{ in} \times 6 \div (.289) 16^3 = 19,000 \text{ psi} < 55,000 \text{ psi}$$

Shear Load on Bolt,  $P_s$

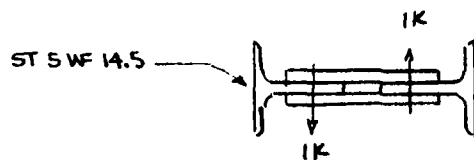
$$P_s = \frac{85,200}{3} \rightarrow 85,200 \times 3.25 \div 8.5 = 43,218$$

AN16 rated in single shear 58,900 lb.

Coupler Rates =  $9 \times 3/4 \times 12$

$$f_b = 6 (85,200 \times 4.5) \div 2 \times .75 \times 12^2 = 10,650 \text{ psi} < 55,000 \text{ psi}$$

COUPLER ARRANGEMENT L-00670

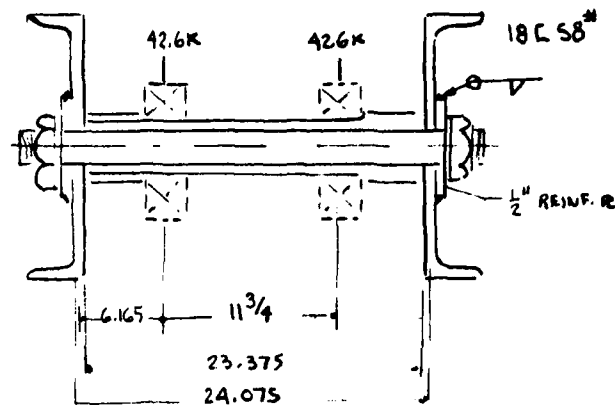


Assume a 1000 lb. side force due to transverse loading on the basis of tire friction plus guide offering maximum resistance. By inspection the stem of structural tee is the weakest section

Bending Stress,  $f_b$

$$f_b = \frac{6 (1000 \times 2.75)}{16 \times .289^2} \quad 12,347 \text{ psi} < 55,000 \text{ psi}$$

# DEADLOAD SHAFT L-00673

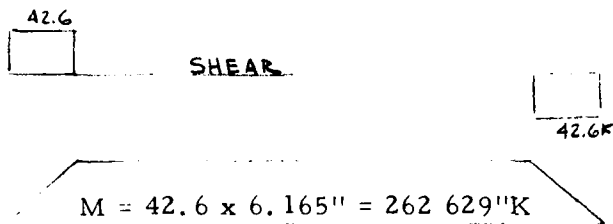


Shaft Mat'l. 4130

$F_{tu} = 90 \text{ ksi}$

$F_{ty} = 70 \text{ ksi}$

The center bearings and centerline of reaction will be considered equidistant reactions are located 6.165 inches from bearing



Section Modulus  $Z_1$

$$Z_1 = .0983 \left\{ \frac{3.68^4 - 2.5^4}{3.68} \right\} = 3.855 \text{ in.}^3$$

$$Z_2 = .0982 (2.5^3) = 1.534 \text{ in.}^3$$

Distribution of Moment  $Z_n/Z_{\text{total}}$

$$M \frac{3.855}{5.3894} = .7153M = 187,858 \text{ in.lb.}$$

$$M \frac{1.534}{5.3894} = .2847M = 74,770 \text{ in.lb.}$$

DEADLOAD SHAFT L-00673

Bending Stress of Bar Section

$$f_{\text{bar}} = 77,770/1.534 = 48,742 \text{ psi}$$

Bending Stress of Tube Section

$$f_{\text{tube}} = 187,858/3.855 = 48,731 \text{ psi}$$

$$DM = \frac{70,000}{1.15 \times 48,742} - 1 = .25$$

Shear Stress in 2-1/2 in. dia. bar

$$f_s = \frac{4 V}{3 A} = \frac{4 \times 42,600}{3 \times 4.909} = 11,570 \text{ psi}$$

$$DM = \frac{55\% 170,000}{1.15 \times 115\%} - 1 = 1.89$$

Bearing Stress @ Reaction Point (18 C 58)

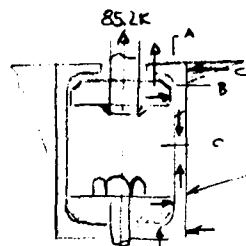
$$f_{\text{br}} = \frac{42,600}{2.5'' \phi \times .7''} = 24,343 \text{ psi}$$

$$DM = \frac{60,000}{1.15 \times 24,343} - 1 = 1.14$$

Strongly recommend reinforcing rings welded to 18 C 58<sup>th</sup> to increase bearing surface and to minimize stress concentration factor effect. Steps to prevent fatigue failure

## REMOVABLE TRACK L-00666

Maximum loading imposed on track occurs during a 2G vertical upload transferred by means of the guides.



$$170,400 \text{ lb.} \times 2 \text{ G's} / 4 \text{ guides} = 85,200 \text{ lb.}$$

9C 23.9 (MODIFIED)

Bending Stress @ Fillet Radius of Channel Flange

$$\begin{aligned} f_b \text{ sect. AA} &= 6M/bt^2 \\ &= 6(42,600) \times .75/10 \text{ in.} \times .75^2 \\ &= 34,080 \text{ psi} < 36,000 \text{ psi} \\ f_{\text{shear}} &= 42,600/10 \text{ in.} \times .75 \\ &= 5680 \text{ psi} \end{aligned}$$

Since the heel of channel bears against runway member it will cause flange adjacent to slipper to deflect inward thereby reacting entire moment as a couple

$$\begin{aligned} f_t \text{ Sect. BB} &= \frac{42,600}{12 \times .4375} + \frac{6 \{42,600 \times (1 - .75)\}}{12 \times .4375^2} = 8114 + 27,820 \\ &= 35,934 \text{ psi} < 36,000 \text{ psi} \end{aligned}$$

### Attachments

Load distribution to attachments assumed lagged out equivalent to depth of channel or  $2 \times 9 + 10'' = 28$  inch. Assume 7/8 in Phillips Anchor Bolts.

No. of Bolts Required, N

$$\begin{aligned} N &= 85,200 \text{ lb.} / 19,442 \times 80\% \\ &= 5.5 \text{ bolt} \end{aligned}$$

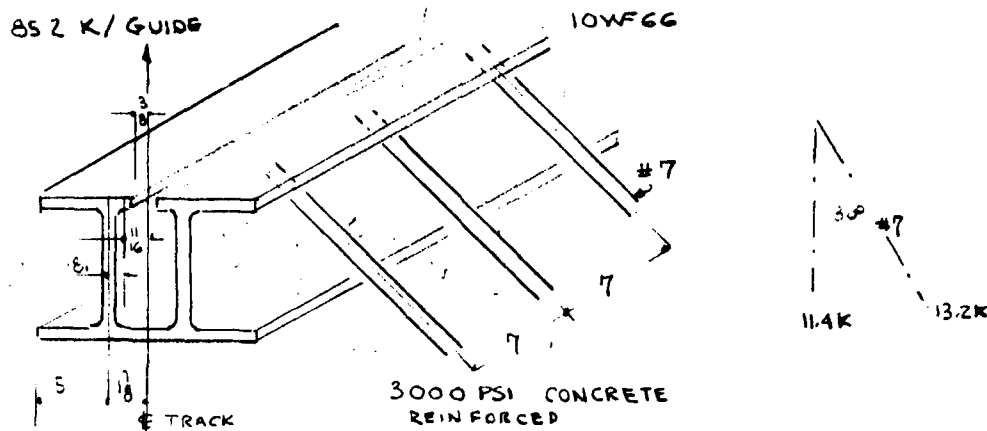
Bolt Spacing, S

$$S = 28 \text{ inches} / 5.5 \text{ bolts} = 5.0 \text{ inches} > 4.00 \text{ in. minimum}$$

Minimum spacing required for 100% efficiency 8 inches and for 80% efficiency 4 inches.



FIXED TRACK L-00666



Loading imposed on track occurs during a 2G vertical upload transferred by means of a guide. The load is reacted via the W beam into concrete and the concrete bonding stress and shear stress.

Stress on W lip (assume 12 in. effective length),  $f_b$

$$f_b = 6 \times 85,200\# \times .81 \text{ in}/2 \text{ sides} \times 12 \text{ in} \times .748^2 = 30,836 \text{ psi} < 36 \text{ ksi}$$

Shear resistance of concrete both sides and considered load lagged equivalent to beam depth.

$$F_S = \frac{2 \text{ sides} \times (10 \text{ in.} + 10 \text{ In. lagging}) \times 10 \text{ in. depth} \times 75 \text{ psi}}{1000 \text{ lb./kip.}} = 30\text{K}$$

Shear resistance of #7 bars over effective 20 inch distance

$$F_{S\#11} = \frac{2 \text{ sides} \times 3 \text{ bars} \times 2.749 \text{ in} \times 20 \text{ in length} \times 240 \text{ psi} \times \cos 30^\circ}{1000 \text{ lb/kip}} = 68.6\text{K}$$

---


$$98.6\text{K}$$

85.2 K required < 98.6K provided

## J-79 JET CAR

Below is a list of data employed in the analysis of the J-79 jet car and the sketch of jet car appears on page \_\_\_ with various notations.

Weights are considered approximate for this analysis.

### Concentrated Loads

E = Engine 4 @ 3685	14,740 lb.
(Thrust 15,600 lb. each)	
Loads beamed to mtg. points	
$R_A = 3685 \times 70/104.35 = 2472 \text{ lb.}$	
$R_F = 3685 \times 34.35/104.35 = 1213 \text{ lb.}$	
3685 lb.	
F = Fuel Tank (Full) 2 @ 1750	3,500 lb.
G = Guide 4 @ 100	400 lb.
$G_M$ = Guide Mount Plate 4 @ 80	320 lb.
B = Battery 2 @ 100	200 lb.
W = Wheel 4 @ 210	840 lb.
(Static load rating 21,000 lb. each)	
Total	20,000 lb.

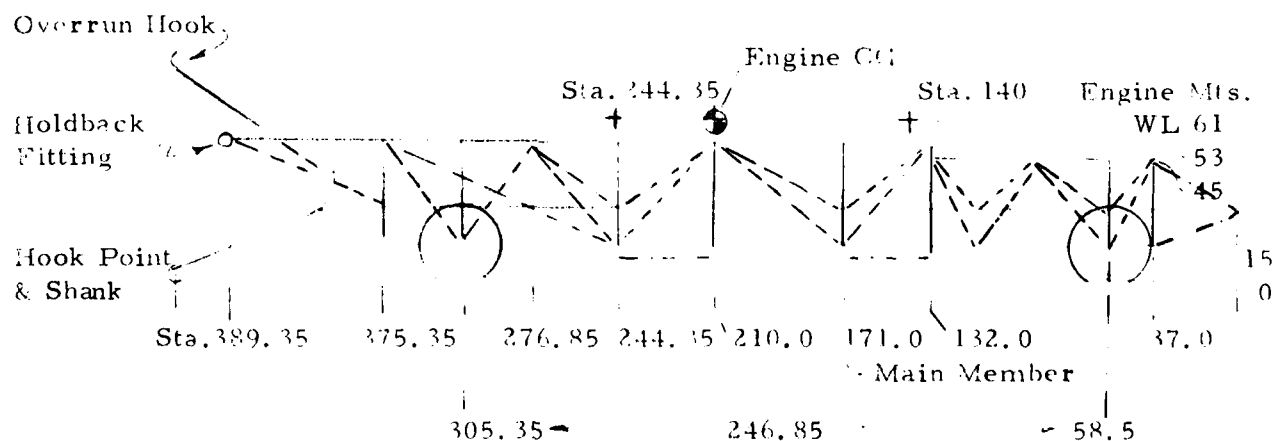
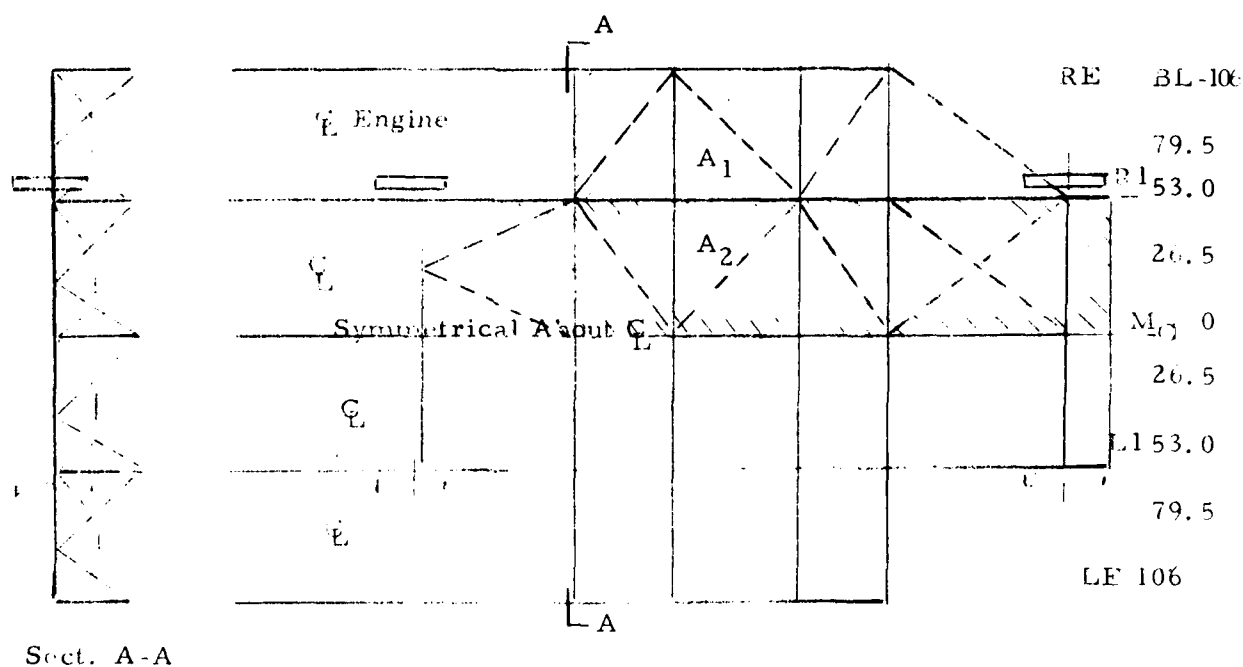
### Assumed Distributed

Framework	10,000 lb.
Fairing Skin & Frames	1,200 lb.
Miscellaneous	3,800 lb.
Total	15,000 lb.

Total weight,  $W_T = 20,000 + 15,000 = 35,000 \text{ lb.}$

The distributed weight will be considered to act on plan area designated as  $A_1$ ,  $A_2$ , etc., and delineated by typical shaded zones as shown on sketch of following page. The loading will be considered as panel point loads on trusses.

J-79 JET CAR L-00682



All longitudinal members 4 x 4  $\square$  tube except main member 12 x 4 x 1/2  
 All transverse members 3 x 3  $\square$  tube  
 2 Fuel tanks @ 200 gal/tank  
 2 Batteries, 4-30 x 8.8 tires

## J-79 JET CAR

### Weight Distribution

#### Areas

$$\begin{aligned}A_1 &= A_4 = 53.0 (244.35 - 132.0) = 4,380 \text{ in.}^2 \\A_2 &= A_3 = 53.0 (327.0 - 37.0) = 15,370 \text{ in.}^2 \\A_{\text{total}} &= A_T = 2 (A_1 + A_2) = 39,500 \text{ in.}^2\end{aligned}$$

#### Total Distributed Weight, TDW

$$\begin{aligned}\text{TDW Entire car} &= 15,000 \text{ lb. (ref. page )} \\ \text{TDW on } A_1 \text{ \& } A_4 &= 15,000 A_1/A_T = 1663 \text{ lb.} \\ \text{TDW on } A_2 \text{ \& } A_3 &= 15,000 A_2/A_T = 5837 \text{ lb.}\end{aligned}$$

#### Load/Inch on Center Truss, $W_1$

$$W_1 = \frac{\text{TDW } A_2}{2} + \frac{\text{TDW } A_3}{2} = \frac{5837}{290} = 19.65 \text{ lb./in.}$$

#### Load/Inch on Outer Truss ( $L_E$ or $R_E$ ), $W_3$

$$W_3 = \frac{\text{TDW } A_1}{2} = \frac{756}{112.35} = 6.73 \text{ lb./in.}$$

#### Load/Inch on Interior Truss ( $L_1$ or $R_1$ ), $W_2$

$$W_2 = \frac{W_1}{2} + W_3 = \frac{19.65}{2} + 6.73 = 16.56 \text{ lb./in.}$$

#### Engine Load Distribution to Mounts

(Repeated)

$$R_{\text{aft}} = 3685 \times 70/104.35 = 2472 \text{ lb.}$$

$$R_{\text{fwd}} = 3685 \times 34.35/104.35 = \frac{1213 \text{ lb.}}{3685 \text{ lb.}}$$

# J-79 JET CAR

## Center Frame Loads

Distributed load,  $W_1$  of 19.69#/in. - Engine weight - & fuel tank

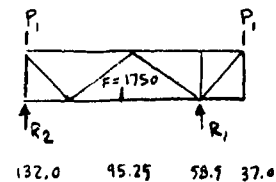
### Sta. 37.0 to 132.0

Panel Point Load (P.P.L),  $P_1$

$$P_1 = 19.65 (132.0 - 37.0)/2 = 933 \text{ lb.}$$

$$R_1 = \frac{F + 95.0P}{2 \cdot 73.5} = 2081 \text{ lb.}$$

$$R_2 = \frac{F}{2} + P - \frac{21.5P}{73.5} = 1535 \text{ lb.}$$



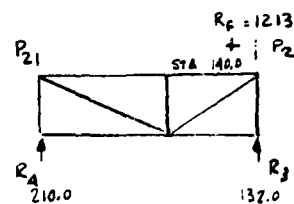
### Sta. 132.0 to 210.0

PPL,  $P_2$

$$P_2 = 19.65 (210.0 - 132.0)/2 = 766 \text{ lb.}$$

$$R_3 = P_2 + \frac{70}{78} (1213) = 1855 \text{ lb.}$$

$$R_4 = P_2 + \frac{8}{78} (1213) = 890 \text{ lb.}$$



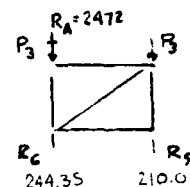
### Sta. 210.0 to 244.35

PPL,  $P_3$

$$P_3 = 19.65 (244.35 - 210.0)/2 = 338 \text{ lb.}$$

$$R_5 = P_3 = 338 \text{ lb.}$$

$$R_6 = P_3 + 2472 = 2810 \text{ lb.}$$



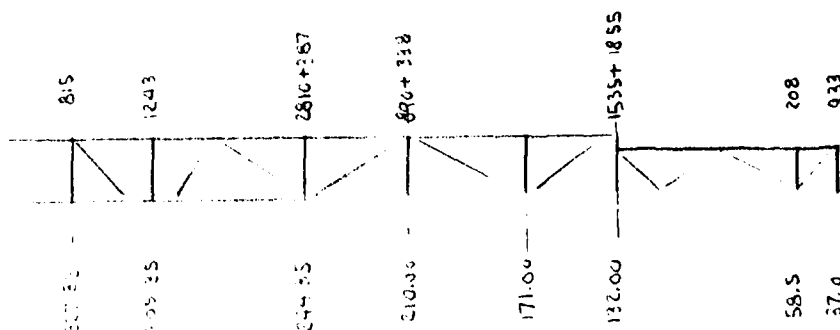
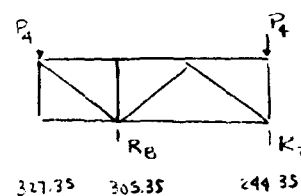
### Sta. 244.35 to 327.35

PPL,  $P_4$

$$P_4 = 19.65 (327.35 - 244.35)/2 = 815 \text{ lb.}$$

$$R_7 = P_4 = 32 P_4 / 61.0 = 387 \text{ lb.}$$

$$R_8 = 93 P_4 / 61.0 = 1243 \text{ lb.}$$



# J-79 JET CAR

## Interior Frame Loads

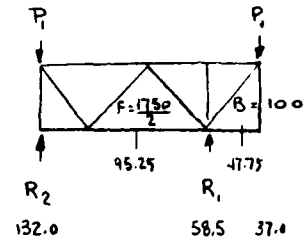
Distributed load,  $W_2$  of 16.56#/in. - engine weight - fuel tank - battery, guides, and guide mounting.

Sta. 37.0 to 132.0  $W_{2x} = 19.65/2$

Panel Point Load (PPL),  $P_1$   
 $P_1 = \frac{19.65 (132.0 - 37.0)}{2} = 466 \text{ lb.}$

$R_1 = \frac{F}{4} + \frac{95.0}{73.5} P_1 + \frac{B \times 84.25}{73.5} = 1154 \text{ lb.}$

$R_2 = \frac{F}{4} + P_1 - \frac{21.5}{73.5} P_1 - \frac{10.75}{73.5} B = 752 \text{ lb.}$

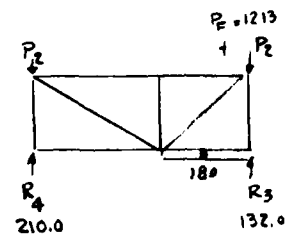


Sta. 132.0 to 210.0

PPL,  $P_2$   
 $P_2 = 16.56(210.0 - 132.0)/2 = 646 \text{ lb.}$

$R_3 = P_2 + \frac{70}{78} (1213) + 180 \times 58.5/78 = 1870 \text{ lb.}$

$R_4 = P_2 + \frac{8}{78} (1213) + 180 \times 19.5/78 = 815 \text{ lb.}$

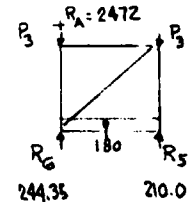


Sta. 210.0 to 244.35

PPL,  $P_3$   
 $P_3 = 16.56 (244.35 - 210.0)/2 = 286 \text{ lb.}$

$R_5 = P_3 + 90 = 376 \text{ lb.}$

$R_6 = P_3 + 2472 + 90 = 2848 \text{ lb.}$

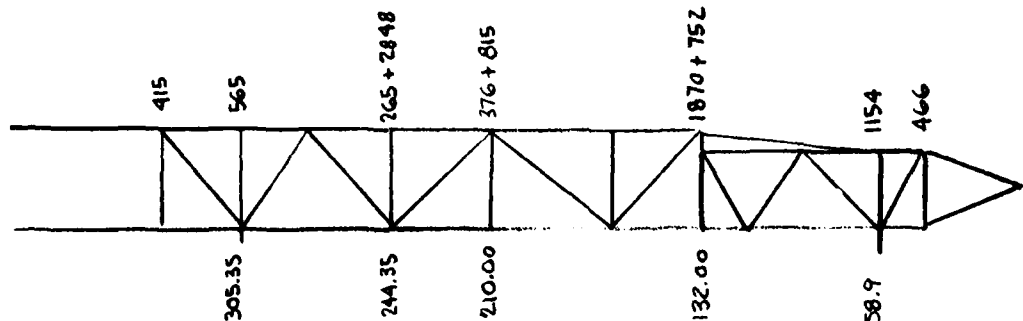
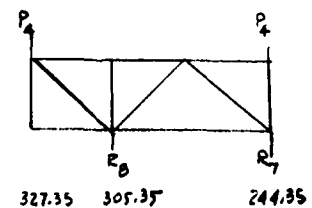


Sta. 244.35 to 327.35  $W_{2x} = 19.65/2$

PPL,  $P_4$   
 $P_4 = 9.825 (327.35 - 244.35)/2 = 415 \text{ lb.}$

$R_7 = P_4 - 22 P_4/61.0 = 265 \text{ lb.}$

$R_8 = 83 P_4/61.0 = 565 \text{ lb.}$



# J-79 TEE CAR

## Outside frame loads

Distributed load,  $W_3$  of 6.73 lb./in & 1/2 engine weight

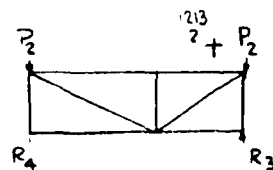
### Sta. 132 to 210.0

PPL,  $P_2$

$$P_2 = 6.73 (210 - 132) / 2 = 262 \text{ lb.}$$

$$R_3 = P_2 + 70 \times 606.5 / 78 = 806 \text{ lb.}$$

$$R_4 = P_2 + 8 \times 606.5 / 78 = 324 \text{ lb.}$$



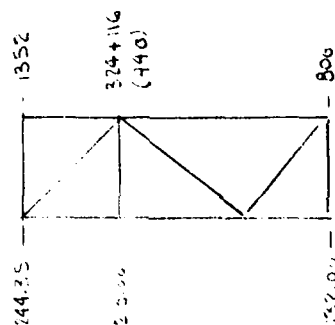
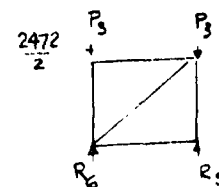
### Sta. 210 to 244.35

PPL,  $P_3$

$$P_3 = 6.73 (244.35 - 210) / 2 = 116 \text{ lb.}$$

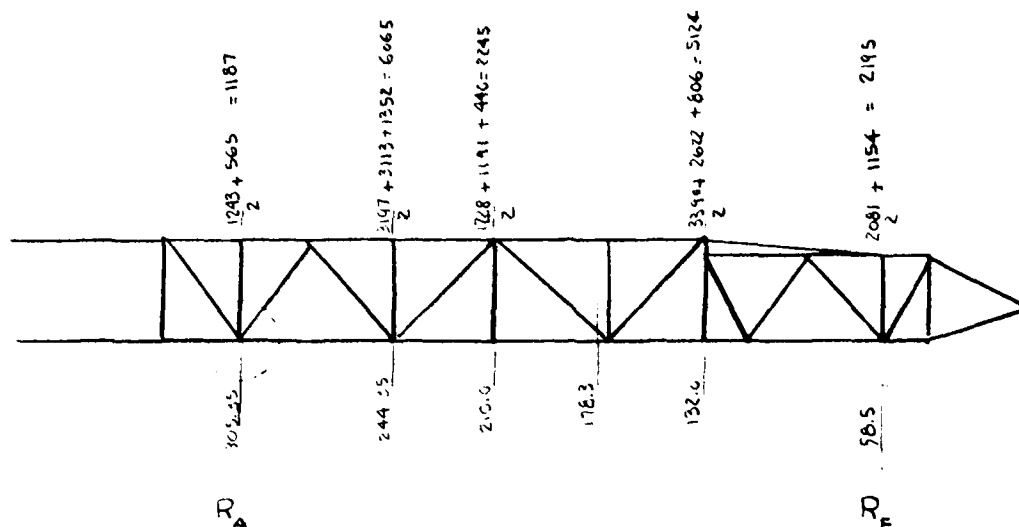
$$R_5 = P_3 = 116 \text{ lb.}$$

$$R_6 = P_3 + 1236 = 1352 \text{ lb.}$$



# J-79 JET CAR

## Vertical Loads with Wheels Reaction



$\Sigma$  of Loads = 16,816# < 17,500# - Acceptable for this preliminary analysis  
neglected wheels 420#

$$R_A = \frac{2195 \times 0 + 5124 \times 73.5 + 2245 \times 151.5 + 6065(185.85) + 1187(246.85)}{246.85}$$

$$= 8657 \text{ lb.}$$

$$R_F = 16,816 - R_A = 8159 \text{ lb.}$$

$$\text{C.G. approx.} = \frac{8159 \times 246.85}{16,816} + 58.5 = 178.3$$

Maximum moment occurs @ sta. 210

$$M_{\max} = 95.35(8657 - 1187) - 34.35(6065) = 503,932 \text{ in. lb.}$$

Tension & Compression in Longitudinal Beams

$$T = C = M_{\max} / (53 - 15) = 13,261 \text{ lb.}$$

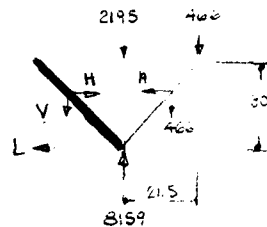
$$f_c = 13,261 / 5.4376 = 2438 \text{ psi (assume a } 4 \times 4 \times 3/8 \text{ tube)}$$

$$\text{Slenderness ratio } \frac{L}{r} = \frac{40}{2 \times 1.481} = 13.5 \text{ (low)}$$



# F-79 JET CAR

The following joint analysis is an effort to size truss members.



$$\begin{aligned} h &= 466 \times 21.5/30 = 334 \\ V &= 8159 - 2195 - 466 = 5498 \\ H &= 5498 / \cos 45^\circ = 3887 \\ V \rightarrow H &= 7775 \\ L_L &= H - h = 3887 \end{aligned}$$

Assume strut load tripled or  $3 \times 7775 = 23,325$  lb. and  $3 \times 3 \times 1/4$  tube

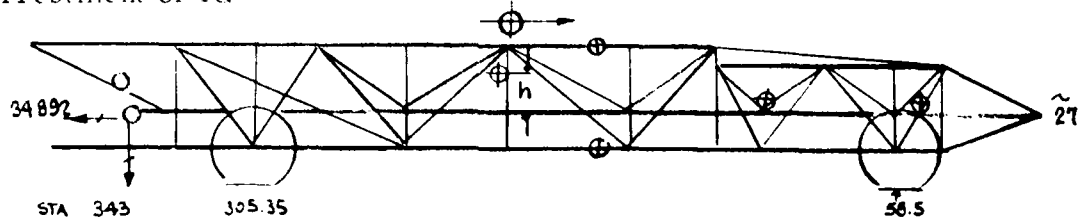
$$f_c = 23,325 / 27,501 = 23,322 \text{ psi}$$

$$\text{Slenderness ratio, } \frac{l}{r} = \frac{43.0}{2 \times 1.1274} = 19 \text{ (negligible)}$$

$$DM = \frac{36,000}{1.15 \times 23,322} - 1 = .34$$

## J-79 JET CAR

### Arrestment of 1G



Engine 4 @	3658	(61.0-27)	=	497,488
U-frame	7500	(530-27)	=	195,000
L-frame	7500	(15-27)	=	- 97,500
Fuel Tank	3500	(25-27)	=	- 7,000
Battery	200	(25-27)	=	- 400
Guide Mtg Pl	320	(15-27)	=	- 4,160
Guide	400	(7.5-27)	=	- 7,800
Wheels	840	(15-27)	=	- 10,920
M =				564,708 in.lb.

Assume Moment distributed as couple between front tires & hook point joint.

$$V = M / (343 - 58.5) = 1985 \text{ lb.}$$

The gravity load @ sta. 305.35 is 9077 lb./tire which indicates the vertical load induced in main member is too conservative.

$$h = M / 34,892 = 16.18 \text{ in. above } \pm \text{ hook point joint}$$

### Vertical 1G load

$$\left. \begin{array}{l} R_A = 8579 \text{ lb./tire} \\ R_P = 9077 \text{ lb./tire} \end{array} \right\} \text{previous sheet}$$

The analysis is a preliminary effort in sizing truss members based on company's past performance. The results are not to be interpreted as final for that effort, definite design criteria must be established and a detail analysis must be performed.

AD-A088 359

ALL AMERICAN ENGINEERING CO WILMINGTON DE  
FEASIBILITY AND CONCEPTUAL DESIGN STUDY TO ADD A DEADLOAD TEST --ETC(U)  
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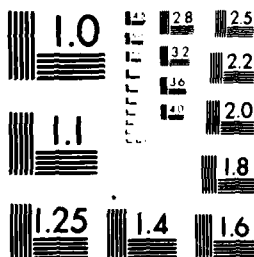
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12. SPONSORING MILITARY ACTIVITY

DCS/Plans and Requirements

AFFTC (XO)

Edwards AFB, California

sibility and design study was conducted to provide design  
and cost estimates for a proposed expansion of the air-  
ng systems and hooks at the Air Force Flight Test Center  
tems Test Complex. A requirement exists for the develop-  
ing of high energy arresting gear systems capable of  
craft at engaging speeds of 235 knots. This study pro-  
of unmanned test vehicles, called deadloads, to be used  
ed range considered safe for live, manned aircraft test  
nd a facility with a total energy capability 10 to 12  
ability of any existing facility in this country. The  
ncept chosen is a variable weight modular deadload pushed  
rbojet engine car (jet car) coupled to the deadload. Two  
ng different power characteristics are proposed for short  
e test requirements. Engines selected are the J79-5 and  
39's based on present and future availability. Meeting  
requirements of the complete spectrum of aircraft (pro-  
ial passenger and cargo aircraft as well as military) will  
ddition of a 2000 foot long x 50 foot wide extension to  
runway.

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
gh speed aircraft arrestments rcraft arresting systems avy weight aircraft arrestments rcraft arresting hooks riable weight modular deadload t car 9-5 engine -39 engine r Force Flight Test Center wards AFB sign requirements st estimates						